VOL. IV OCTOBER, 1917 No. 4

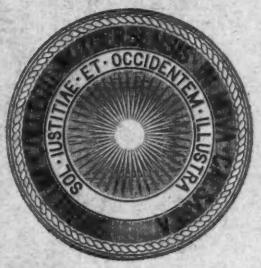
SOIL SCIENCE

FOUNDED BY

RUTGERS COLLEGE

NEW BRUNSWICK, N. J.

CHEMICAL LIBRARY
OCT 22 1917
UNIV. OF MICH.
LIBRARY



JACOB G. LIPMAN, Editor-in-Chief

CARL R. WOODWARD, Assistant Editor

IN CONSULTATION WITH

DR. F. J. ALWAY
University of Minnesota, St. Paul, Minn.
DR. C. BARTHEL
Centralanstalten för Försöksväsendet på Jordbruksområdet, Stockholm, Sweden
DR. M. W. BEIJERINCK
Technische-Hoogeschool, Delft, Holland
PROF. A. W. BLAIR
Rutgers College, New Brunswick, N. J.
DR. P. E. BROWN
Iowa State College of Agriculture, Ames, Iowa
DIRECTOR H. R. CHRISTENSEN
Statens Plantevls-Laboratorjum, Copenhagen, Denmark
DR. H. J. CONN
New York State Experiment Station, Geneva, N. Y.
DR. H. VON FEILITZEN
Svenska Mosskulturföreningen, Jönköping, Sweden
DR. E. B. FRED
University of Wisconsin, Madison, Wis.
DR. R. GREIG-SMITH
Linnean Society, Sydney, New South Wales
DR. B. L. HARTWELL
Rhode Island Experiment Station, Kingston, R. I.
DR. C. B. LIPMAN
University of California, Berkeley, Calif.
DR. F. LÖHNIS
U. S. Department of Agriculture, Washington, D .C.
DR. T. L. LYON
Cornell University, Ithaca, N. Y.
DR. E. A. MITSCHERLICH
University of Königsberg, Prussia
PROF. C. A. MOOERS
Tennessee Experiment Station, Knoxville, Tenn.
DR. THEO. REMY
Instut für Böden-u. Pflanzenbaulehre, Bonn a. Rhein
PROF. G. ROSSI
Royal Agricultural High School in Portici, Naples, Italy
DR. E. J. RUSSELL
Rothamsted Experiment Station, Harpenden, England
DR. O. SCHREINER
U. S. Department of Agriculture, Washington, D. C.
DR. A. A. F. DE SIGMUND
Technische-Hochschule, Budapest, Hungary
PROF. CHAS. E. THORNE
Ohio Experiment Station, Wooster. Ohio
DR. N. TULAIKOFF
Forest Institute, Petrograd, Russia

PUBLISHED MONTHLY BY
WILLIAMS & WILKINS COMPANY
BALTIMORE, MD., U. S. A.
THE CAMBRIDGE UNIVERSITY PRESS
FETTER LANE, LONDON, E. C.

Entered as second-class matter August 23, 1917, at the post office at Baltimore, Maryland, under the act of March, 3, 1879.

SOIL SCIENCE

Contents for October, 1917

P. E. Brown and H. W. Warner. The Production of Available Phosphorus from Rock Phosphate by Composting with Sulfur and Manure 269

A. W. Blair and H. C. McLean. Total Nitrogen and Carbon in Cultivated Land and Land Abandoned to Grass and Weeds 283

Clayton O. Rost. The Determination of Soil Phosphorus 295

Louis J. Gillespie and Lewis A. Hurst. Hydrogen-ion Concentration Measurements of Soils of Two Types: Caribou Loam and Washburn Loam 313

K. Miyake. Further Studies of the Nature of Ammonification 321

P. S. Burgess. Nitrification as a Measure of the Availability of Different Forms of Calcium Carbonate when Employed as Correctors of Soil Acidity 327

Jacob G. Lipman and Harry C. McLean. Vegetation Experiments on the Availability of Treated Phosphates 337

SOIL SCIENCE

Published Monthly. Two volumes (1000 pages) a year are issued. Illustrated.

PRICES

		U. S. and Dependencies	Canada	Foreign
Volume IV (Numbers 1-6 inclusive) Volume V (Numbers 1-6 inclusive)	(July 1917—June 1918)	$4.00	$4.25	$4.50
Volume III (January—June, 1917)		3.00	3.15	3.25
Volume II (July—December, 1916)		3.00	3.15	3.25
Volume I (January—June, 1916)		3.00	3.15	3.25

Williams & Wilkins Company

Publishers :: :: Baltimore, U. S. A.

Beutelspacher y Cia.
Sarmiento 815, Buenos Aires

Cambridge University Press
Fetter Lane, London

Maruzen and Co.
Nihonbashi Tori-Sanchome, Tokyo

THE PRODUCTION OF AVAILABLE PHOSPHORUS FROM ROCK PHOSPHATE BY COMPOSTING WITH SULFUR AND MANURE

P. E. BROWN AND H. W. WARNER

Iowa Agricultural Experiment Station

Received for publication August 10, 1917

Ever since the days of Liebig, the need of the return to the soil of the phosphorus removed by crops has been recognized. Various phosphorus-containing materials have been and are still being employed as fertilizers but the discovery of the extensive deposits of mineral phosphates in various parts of this country has made these materials, at this time, the chief source of phosphorus for general fertilization purposes.

The phosphorus in these mineral phosphates is in an unavailable form and they have been treated commercially with sulfuric acid to produce available phosphorus or "acid phosphate." Considerable expense is involved in this process with the consequent effect that the phosphorus in acid phosphate costs the farmer more than twice as much as that in the raw rock. Attempts have therefore been made from time to time to devise some practical method of treating the raw material on the farm, either before or after application to the soil, to make it available. Many experiments have been carried out, mixing the phosphate with decaying organic matter, but the results have been far from satisfactory. The investigations have been summarized by Lipman, McLean and Lint (5, 6) and the conclusion seems well warranted that this production of acid phosphate on the farm by composting with organic materials is at best a very uncertain process.

The above-mentioned authors suggested the use of free sulfur with rock phosphate to make the phosphorus available. The sulfur is oxidized rapidly in the soil through the action of microörganisms and the sulfuric acid produced reacts with the raw rock, producing acid phosphate in much the same way as the latter material is obtained commercially. This method of producing available phosphorus was tested with several soils and was found to be very efficient in all cases. The soil containing the largest amount of organic matter was found, however, to lead to the greatest increase in available phosphorus. The authors conclude that in field practice, inert phosphates may best be made available by sulfur oxidation in a compost heap containing a relatively large proportion both of phosphate and sulfur.

From a consideration of the investigations briefly referred to above and the conclusions drawn from them, it seemed that acid phosphate might be produced on the farm to good advantage by composting the raw rock with

sulfur and manure. A double purpose might thus be accomplished, not only by producing available phosphorus, but in conserving the manure. Just how efficient such a method of conservation of the valuable portions of manure might be, remains to be ascertained in future studies. The present work is concerned only with the changes which the phosphorus and the sulfur undergo in the manure heap.

Furthermore, if it were possible to produce acid phosphate in the manure heap by composting not only would there be a large saving in the cost of the phosphorus applied to the soil, but also the expense of application would be lessened.

The purpose of the experiments reported in the following pages was therefore to ascertain the feasibility of producing acid phosphate on the farm by composting rock phosphate with sulfur and various farm manures.

EXPERIMENTAL

It was realized that one of the chief factors involved in the success of the process would be the efficiency of the sulfofying flora of the manure. Accordingly, a preliminary series was planned to throw some light on this point and to compare the sulfofying floras of the manures to be tested with that of a rich loam.

One-hundred-gram quantities of an air-dry silt loam were weighed out in tumblers. Each portion of soil received an addition of 100 mgm. of flowers of sulfur, which were thoroughly stirred in. Duplicate portions of the soil were then inoculated with 5 cc. of infusions of compost, horse manure, cow manure and fresh soil, respectively. Water was added in sufficient amounts to bring the content of the soils up to the optimum. The mixtures were incubated for 10 days at room temperature. At the end of that time the sulfates were extracted by shaking with water for 7 hours and determined photometrically according to the method of Brown and Kellogg (2).

The results of this test were as follows:

INFUSION	MGM. OF SULFUR AS SULFATE	AVERAGE
Compost	60.80	
	62.80	61.80
Cow manure	61.20	
	62.80	62.00
Horse manure	62.80	
	64.40	63.60
Loam	62.80	
	62.00	62.40

It is apparent from these results that each of the manures in question has a sulfofying flora practically as efficient as that of the rich loam. The horse

manure seemed to give a slightly more vigorous action than the other manures and the soil, but the differences were too small to be distinctive. In every case over 60 per cent of the sulfur added was transformed to sulfates. This would indicate clearly that the manures and the soil tested contain sulfofiers of such efficiency and in such abundance as to insure a rapid production of sulfates in the field.

PLAN OF THE EXPERIMENT

The experiment was arranged in three series, a different manure being used in each. Compost, cow manure, and horse manure were used in series A, B and C, respectively.

The compost consisted of a mixture of horse manure, cow manure, straw, hay, and other litter. It represented fairly well the contents of the ordinary manure pile or pit. This material was dried, ground, mixed and analyzed for total phosphorus. The phosphorus content was found to be 0.3232 per cent, on the dry basis.

The horse manure and cow manure were fresh, unfermented materials and contained no straw or litter of any kind. These were treated in the same manner as the compost. The phosphorus content was found to be 0.6051 and 0.5165 per cent, respectively.

The rock phosphate employed was a finely-ground rock, analyzing 12.81 per cent of total phosphorus. Pure precipitated sulfur was used.

Small glass tumblers were used as containers. Therse were fitted with tin covers to prevent excessive evaporation, but loosely enough to permit adequate aeration. In each tumbler was placed 25 gm. of the dry manure, treated in duplicate, as follows:

Nos. 11 to 15 (inclusive) 25 gm. manure.
Nos. 21 to 25 (inclusive) 25 gm. manure.
Nos. 31 to 35 (inclusive) 25 gm. manure + 4 gm. rock phosphate.
Nos. 41 to 45 (inclusive) 25 gm. manure + 4 gm. rock phosphate
Nos. 51 to 55 (inclusive) 25 gm. manure + 1½ gm. sulfur.
Nos. 61 to 65 (inclusive) 25 gm. manure + 1½ gm. sulfur.
Nos. 71 to 75 (inclusive) 25 gm. manure + 1½ gm. S. + 4 gm. rock phosphate
Nos. 81 to 85 (inclusive) 25 gr. manure + 1½ gm. S. + 4 gm. rock phosphate.

Each series was treated the same, the only difference being in the manure used. All additions were thoroughly mixed with the manure and the contents of each tumbler were inoculated with 2 cc. of a corresponding infusion of fresh manure. Sufficient water was added to bring the contents of the soils up to the optimum and they were incubated at room temperatures, the water lost by evaporation being restored every three weeks.

The entire contents of the pots were taken for analysis. This was done in order to eliminate the possibility of not securing representative portions of the mixtures. Determinations of available phosphorus were made at the following intervals:

Nos. 11, 21, 31, 41, at beginning (no fermentation).
Nos. 12, 22, 32, 42, after 6 weeks' fermentation.
Nos. 13, 23, 33, 43, after 9 weeks' fermentation.
Nos. 14, 24, 34, 44, after 12 weeks' fermentation.
Nos. 15, 25, 35, 45, after 15 weeks' fermentation.

Available phosphorus determinations

The methods now in use for determining available phosphorus are quite arbitrary, and in no way can they be considered even as approximations of the phosphorus actually available for plant use. In this work, the phosphorous was extracted by N/5 HNO_3 with 5 hours' constant shaking at room temperature. The N/5 HNO_3 is perhaps a more active solvent than some of the other extraction-solutions, but it undoubtedly gives dependable comparative results.

Fraps (4), Tottingham and Hoffman (7) and Ames and Gaither (1) have used this acid for phosphorus extraction. The greater convenience of preparing and working with N/5 HNO_3, as compared with some of the other solvents, was also considered in the selection of this solution as the measure of availability.

To determine the available phosphorus by this method the contents of the tumblers were transferred to shaker bottles with 250 cc. of N/5 HNO_3. These were shaken for 5 hours in a mechanical shaker. The contents were filtered and duplicate 50-cc. portions of the filtrate were evaporated to dryness with 5 cc. of $Mg(NO_3)_2$. The residues were ignited and dissolved in HNO_3 and a little HCl. The phosphorus was then precipitated in the usual way and determined volumetrically.

Series A

In table 1 are given the results of the determinations made in Series A where compost was used as the manure with which the floats and sulfur were composted.

TABLE 1

Determinations of available phosphorus when compost was used

	COMPOST	COMPOST AND SULFUR	INCREASE DUE TO SULFUR	COMPOST AND FLOATS	COMPOST, SULFUR AND FLOATS	INCREASE DUE TO SULFUR
	mgm.	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*
Total Phosphorus	80.8	80.8		593.2	593.2	
Time:						
At beginning	49.3	49.3	0.0	289.9	289.9	0.0
End of 6 weeks	47.9	56.9	9.0	249.5	342.2	92.7
End of 9 weeks	58.3	63.3	5.0	255.5	371.0	115.5
End of 12 weeks	59.9	63.3	3.4	268.9	395.4	126.5
End of 15 weeks	57.6	60.9	3.3	272.9	428.6	155.7

It is evident from these figures that in the untreated compost, fermentation caused a rather noticeable increase in available phosphorus which apparently reached its maximum at the end of 9 weeks, the variations after that time being too small to be distinct. The compost treated with sulfur gave a similar increase, which was slightly greater than where no sulfur was added. The addition of sulfur apparently enhanced the solubility of the phosphorus although to a rather limited extent. When rock phosphate, containing

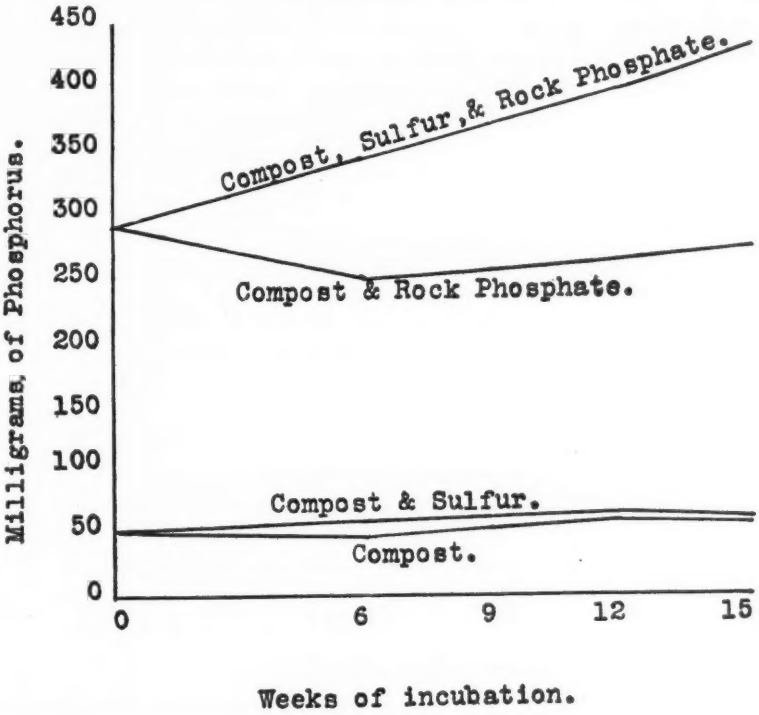


FIG. 1. DIAGRAM SHOWING DETERMINATIONS OF AVAILABLE PHOSPHORUS WHEN COMPOST WAS USED

512.4 mgm. of phosphorus, was added to the manure, there occurred at the beginning, an enormous increase in available phosphorus. This increase represented 45 per cent of the total phosphorus in the mixture. Evidently the solution used for extraction dissolved much more phosphorus from the floats than would be readily available to plants. Six weeks of fermentation caused a very noticeable depression in phosphorus-availability. After that time, however, there was a continuous, gradual increase, up to 15 weeks, but at that time the original degree of solubility had not quite been attained.

With longer incubation, further increases in available phosphorus might have occurred and the amount produced might have been far in excess of that obtained at the beginning.

Where sulfur was present with the compost and floats an unquestionable increase in availability was found. With only 6 weeks' composting, the sulfur caused a greater solubility of phosphorus by 92.7 mgm., as compared with the mixtures containing no sulfur. The increases became greater at each sampling until at the final date a gain of 155.7 mgm. of phosphorus, or 26 per cent of the total phosphorus present, was obtained, due to the action of the sulfur. The addition of sulfur to the floats and manure evidently not only offset the depression brought about in the mixture of compost and floats, but caused a very marked gain in the solubility of the phosphorus in the floats. The results obtained in this series furnish very definite evidence in support of the theory that the phosphorus in floats may be made available by composting with manure and sulfur. The results of Series A, as given in table 1, are shown graphically in figure 1.

Series B

The results given in table 2 show the amounts of available phosphorus found at the various intervals in mixtures of cow manure with floats and sulfur.

TABLE 2

Determinations of available phosphorus when cow manure was used

	COW MANURE	COW MANURE AND SULFUR	INCREASE DUE TO SULFUR	COW MANURE AND FLOATS	COW MANURE, SULFUR AND FLOATS	INCREASE DUE TO SULFUR
	mgm.	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*
Total Phosphorus	129.1	129.1		645.1	645.1	
Time:						
At beginning	103.9	103.9	0.0	307.9	307.9	0.0
End of 6 weeks	79.5	100.3	20.8	284.9	421.5	136.6
End of 9 weeks	80.6	96.6	16.0	297.7	437.9	140.2
End of 12 weeks	81.6	97.6	16.0	285.9	444.5	158.6
End of 15 weeks	83.3	99.3	16.0	279.9	464.2	184.3

It is evident from these data that the availability of the phosphorus in the untreated cow manure was greatly lessened by fermenting for 6 weeks. This is in direct opposition to the corresponding results in the compost series, where an increase in availability was found. After 6 weeks there was a gradual increase in the availability which was so small as to be of no consequence. This decrease in available phosphorus is probably the result of the vigorous action of phosphate-assimilating organisms in the early stages of fermentation in fresh manure.

Where sulfur was added to the manure a very slight decrease in available phosphorus occurred. Here the presence of sulfur practically prevented

any depression in phosphorus-solubility, but did not cause any greater solubility from the original analysis to later ones. Of the 512.4 mgm. of phosphorus in the rock phosphate added to the manure, 204.0 mgm. were found to be soluble, at the first sampling. At later dates smaller amounts of available phosphorus were obtained, the decrease becoming slightly greater at the end of 15 weeks. If the experiment had been continued for a longer

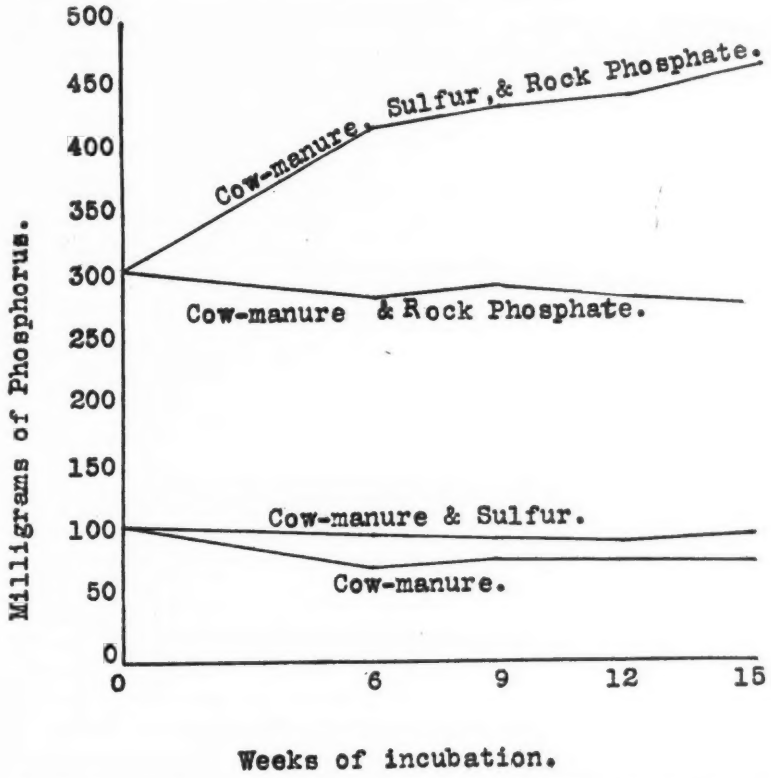


FIG. 2. DIAGRAM SHOWING DETERMINATIONS OF AVAILABLE PHOSPHORUS WHEN COW MANURE WAS USED

time an increase in available phosphorus might have been secured. Evidently the activities of phosphate-assimilating organisms is great enough in the early stages of fermentation of manure to reduce the availability not only of the phosphorus in the manure but of that added in the phosphate.

Where sulfur had been added with the floats the effects on the production of available phosphorus are quite distinct. After 6 weeks of composting, the sulfur produced the remarkable increase of 136.6 mgm. of available

phosphorus over the manure-floats mixtures. Larger increases were found at each succeeding date and the greatest effect of the sulfur was found at the final analysis when 184.3 mgm. of phosphorous were made soluble. This amount equalled 29 per cent of the total phosphorus in the manure and floats. As in the preceding series the action of the sulfur not only overcame the depression in phosphosus-availability in the manure-floats mixture but also brought about a very marked increase in soluble phosphorus at the successive periods of composting. Series B affords additional data confirming the theory that the phosphorus in floats may be made available by composting with manure and sulfur. Figure 2 shows graphically the numerical results expressed in table 2.

Series C

In this series horse manure was used as the medium to which the floats and sulfur were added. The results of the determinations for available phosphorus are recorded in table 3.

TABLE 3

Determinations of available phosphorus when horse manure was used

	HORSE MANURE	HORSE MANURE AND SULFUR	INCREASE DUE TO SULFUR	HORSE MANURE AND FLOATS	HORSE MANURE, SULFUR AND FLOATS	INCREASE DUE TO SULFUR
	mgm.	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*
Total Phosphorus	150.8	150.8		663 2	663.2	
Time:						
At beginning	107.9	107.9	00.0	363.9	363.9	00.0
End of 6 weeks	106.8	110.9	4.1	342.9	415.2	72.3
End of 9 weeks	102.3	113.6	11.3	338.2	433.9	95.7
End of 12 weeks	89.5	113.6	24.1	350.9	451.5	100.6
End of 15 weeks	99.9	112.3	12.4	362.5	481.9	119.4

As in Series B, there was a depression in available phosphorus in the untreated manure. This was greatest at the end of 12 weeks, the final analysis exhibiting a distinct increase in the phosphorus extracted, but the amount was less than that secured in the unfermented manure. Upon addition of sulfur, this depression was eliminated and actual increases over the original analysis are to be noticed. The effect of the sulfur was greatest at the 12 weeks' sampling when its presence caused an increase of 24.1 mgm. of available phosphorus over the manure to which no sulfur had been added.

Of the 512.4 mgm. of phosphorus in the floats added to the manure, 256.0 mgm. are indicated as available, at the first analysis. A decided decrease in available phosphorus then took place until after the 12 weeks' interval, when an increase occurred. The final extraction of the manure-floats mixture was only very slightly less than the original extraction of the same mixture. These results are similar to those secured with the compost and the reverse of those with the cow manure.

Again, the addition of sulfur to the manure and floats appreciably enhanced the solubility of the phosphorus in addition to overcoming the lessened solubility found in the manure-floats mixtures. At the end of the experiment there was an increased availability of 119.4 mgm. of phosphorus, or 18 per cent of the total, which increase was due to the action of the sulfur added.

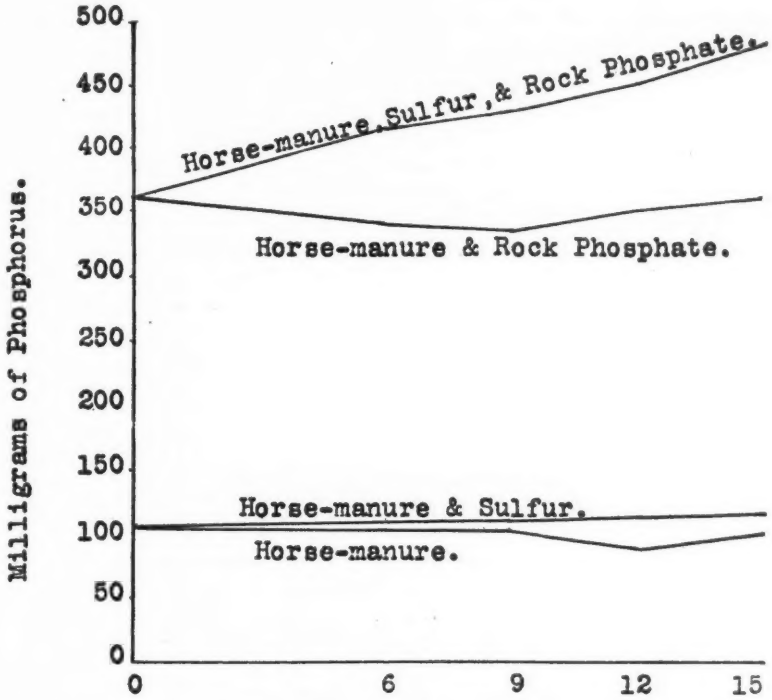


FIG. 3. DIAGRAM SHOWING DETERMINATIONS OF AVAILABLE PHOSPHORUS WHEN HORSE MANURE WAS USED

The results of this series check those of series A and B in substantiating the theory upon which the experiment was based. Figure 3 is the graphic representation of the results tabulated in table 3.

DISCUSSION

For the most part, a rather close agreement is found between the results of these three series. The most noticeable exception to this occurred in the case of the untreated manures, where the fermentation increased the available phosphorus in the compost material but decreased it in both the cow manure and horse manure. The cause of these differences is uncertain but

it is probable that the variations in the physical, chemical and bacteriological conditions of the various manures had much to do in bringing about these results. The depressions found in the amounts of available phosphorus in the horse manure and cow manure agree with the results obtained by Egorov (3). When sulfur was added to the manures there was a more or less apparent gain in available phosphorus, as compared with the untreated manures. In the horse manure-sulfur mixtures and compost-sulfur mixtures, the final results were somewhat higher than the original results. The reverse was true in the cow manure-sulfur mixtures although the difference between the first and last analyses, in this series, was inconsiderable.

Undoubtedly, the method of extracting the available phosphorus indicated a greater amount of phosphorus than would be readily available of plants. Where 512.5 mgm. of phosphorus were added to the manures, increases were found of 240.6 mgm., 204 mgm. and 256 mgm. of soluble phosphorus, in Series A, B and C, respectively, before fermentation. This shows, further, that when the floats were mixed with the various kinds of manures, different amounts of phosphorus were extracted. It would seem that the manures absorbed different quantities of the extracting-acid, thus leaving unequal amounts of this solution free to act upon the particles of floats. It is possible, too, that one kind of manure may have offered more physical protection to the floats particles than did another kind. Although N/5 HNO_3 probably yielded high absolute amounts of available phosphorus, it undoubtedly yielded reliable comparative amounts.

In each of the three series, fermentation depressed the solubility of the phosphorus in the manure-floats mixtures. In series C, the final analysis of he manure and floats showed almost the same availability as the first analysis. This would indicate that, after a period of depression, there is a tendency to regain the original solubility. The same phenomenon was found to occur in the compost-floats mixtures. The depression of available phosphorus in the manure and floats is probably attributable to bacterial assimilation of the dissolved phosphorus. The cause of the increases subsequent to the decreases may be that after a certain time the phosphorus-assimilating bacteria cease to develop proportionately to the phosphorus-liberating bacteria, which condition then permits of the accumulation of soluble phosphorus. It is of interest to note that in no case did composting of floats with manure result in increased availability of the phosphoric acid. This agrees well with the results of several other investigations.

The enormous gains in available phosphorus where sulfur was added with the rock phosphate are the significant results of this experiment. These gains in phosphorus-solubility are so consistent and of such magnitude that the effect of the sulfur can hardly be questioned. After 15 weeks of composting the available phosphorus, as a result of the action of the sulfur, amounted to about 24 per cent of the total phosphorus in the mixtures of manure-sulfur-floats in every series. The constant increases in phosphorus-availability

with the successive analyses indicate that, upon longer composting, a greater percentage of the floats would be made available. It is very evident that the sulfur was oxidized to sulfuric acid by the sulfofying organisms introduced in the manure infusions. The sulfuric acid thus formed reacted with the insoluble rock phosphate and produced acid phosphate in the same way that this product is made commercially.

It is a common practice to apply manure with rock phosphate with the idea of making the latter available in the soil. It should be equally practicable to apply a mixture of these materials with sulfur after composting, and especially if the phosphorus can be applied in a more available form.

There are several considerations which must be taken into account in the application of this composting process to farm practice. Some of these are: the ratio of sulfur to the floats and the proportion of these materials to the manure in the composting mixture; the length of time for a maximum production of available phosphorus in the compost; and finally, and most important of all, the economic consideration.

Commercially, acid phosphate is prepared by treating rock phosphate with an equal part by weight of 60 per cent sulfuric acid. About 400 pounds of sulfur are contained in 1 ton of this acid, hence the sulfur and floats should probably be mixed in the proportion of about 1 part of sulfur to 5 parts of floats. The amount of this mixture to use per ton of manure must be governed by the amount of manure and the amount of rock phosphate to be applied. Experiments along this line are desirable, for while there might probably be no fixed mixture which would be the most profitable, there would undoubtedly be a minimum amount of manure which should be used with a certain amount of rock phosphate.

The results of this experiment show that the longest time of composting gave the highest availability of the phosphorus. Ordinarily it would be possible and practicable to allow the late summer, fall and winter manures to compost until spring. This would permit of from 2 to 4 months' composting in which time a sufficient amount of available phosphorus would be produced to meet the early requirements of the crop. The continued action after applying the composted mixture to the soil would make an adequate accumulation of available phosphorus for the later growth of the crop.

To know whether it is economical to produce available phosphorus by this method it must be tested under actual field and crop conditions. Some theoretical estimations can be made, however, which should indicate rather definitely the economy of such a practice. Since the "compost" material used in this experiment most nearly represented the mixed barnyard manures, the calculations should be based on the results in series A. The 25-gm. portion of dry compost was equivalent to 100 gm. of the fresh material. Hence, in the experiment, the floats were added in the proportion of 4 to 100 or 80 pounds of floats per ton of fresh manure. The floats contained 12.81 per cent of phosphorus. Thus 10.25 pounds of the element phosphorus

were added in each 80-pound portion of raw rock. After 15 weeks there was an increased availability equal to 26 per cent of the total phosphorus in the mixture. The total phosphorus in one ton of fresh manure and 80 pounds of floats was 11.85 pounds. Therefore, an increase of 26 per cent of the total phosphorus would be equivalent to 3.08 pounds of available phosphorus per ton of the mixture. Assuming that the N/5 HNO_3 extracted twice as much phosphorus from the mixture as would be readily available to plants, the amount of available phosphorus produced would be reduced to 1.54 pounds. Then, in a 10-ton application of this composted mixture containing 800 pounds of rock phosphate, there would be, presumably, 15.4 pounds of available phosphorus produced in 15 weeks' fermentation. This amount alone is enough for a 90-bushel crop of corn or a 60-bushel crop of wheat. But the production of available phosphorus would not cease upon application of the mixture to the soil. It has been shown that the production of soluble phosphorus by sulfur-oxidization goes on very rapidly in a soil medium. Hence the conclusion seems justified that there would be a continuous action going on in the soil until practically all of the rock phosphate became converted to acid phosphate.

Theoretically, the foregoing discussion and estimates show that a sufficient amount of available phosphorus for crop requirements can be produced by the proposed method, and that the entire application of floats can be made available upon further action in the soil. Rock phosphate costs about $10.00 a ton, including freight, and 400 pounds of sulfur cost about $8.00. Thus the cash investment necessary for making a ton of floats available would be about $18.00. On the basis of 12.81 per cent of phosphorus in rock phosphate, it would be possible to make 256 pounds of available phosphorus at a cost of $18.00, or 7.0 cents per pound of phosphorus. Commercially manufactured acid phosphate costs about 15 cents per pound of phosphorus contained.

From the estimates made above and from the calculations based upon these estimates, it appears highly probable that rock phosphate can be made available in a practical and economical way on the farm. The proposed method is based upon sound bacteriological and chemical principles and is in no way impracticable in its application. Actual field tests must of course be carried out before definite recommendations can be made as to the advisability of adopting this process on the farm.

Series D

As the foregoing experiments indicate rather definitely the possibility of producing available phosphorus by composting rock phosphate with sulfur and manure, it was deemed advisable to determine the effect of thorough mixing or layering of the floats and sulfur with the manure.

Accordingly, a series was planned in which different amounts of rock phosphate and sulfur were added to horse manure, the additions being thor-

oughly mixed in one half of the tumblers and layered in the other half. Rock phosphate was used in 1-, 2-, and 3-gm. quantities with the same proportionate amount of sulfur as was employed in the other series—$1\frac{1}{2}$ to 4. All the tests were made in duplicate. The methods used for inoculation, incubation, sampling, analysis, etc., were the same as described for series A, B and C. Analyses for available phosphorus were made at the beginning, at the end of 3 weeks, and at the end of 6 weeks.

Table 4 shows the arrangement of this series with the results of the determinations of available phosphorus.

TABLE 4

Determinations of available phosphorus when different amounts of rock phosphate and sulfur were used with horse manure

TREATMENT			AVAILABLE PHOSPHORUS		
Manure	Floats	How added	At the beginning	After 3 weeks	After 6 weeks
gm.	*gm.*		*mgm.*	*mgm.*	*mgm.*
25	1	Mixed	188.0	170.7	190.3
25	1	Layered	188.0	170.3	179.5
25	2	Mixed	286.1	271.4	292.7
25	2	Layered	286.1	264.1	278.5
25	3	Mixed	337.2	360.5	389.8
25	3	Layered	337.2	329.7	352.5

Considering the results in this table, it is apparent that the extraction made before fermentation showed nothing of consequence, except that the amount of phosphorus extracted was inversely proportional to the amount of floats added, per gram of the floats used. For instance, where 1 gm. of floats was added to the manure, there were extracted 188.0 mgm. of phosphorus. One additional gram of floats gave an increase of 98.1 mgm of phosphorus. The next additional gram of floats gave an increase of only 51.1 mgm. of phosphorus. Three weeks of fermentation resulted in a decrease in phosphorus-availability in every case, except where 3 gm. of the floats were mixed with the manure. At this time, the advantage of mixing as compared with layering was quite evident, particularly where the larger amounts of rock phosphate were added. The depressions noted were not entirely overcome at the end of 6 weeks. Only where 1 and 2 gm. of floats were layered with the manure did this depression remain at the last sampling. Evidently, small amounts of phosphate mixed with manure and sulfur are not rendered available as rapidly as the larger amounts. The ratio of 3 gm. to 25 gm. of dry manure seems to be the smallest proportion which allows the sulfur to increase the production of available phosphorus.

The final sampling showed a very noticeable gain in availability where the additions were intimately mixed, as compared with the pots in which the additions were layered. In every case, the results of the experiment show

rather distinctly the advantage of thoroughly mixing over layering when sulfur and floats are composted with horse manure. There is evidently also the need of tests to show the proportion of phosphorus and sulfur which should be mixed with manure.

CONCLUSIONS

The results of these experiments would seem to justify the following conclusions.

1. All of the manures and the loam tested contained efficient sulfofying organisms. The variations in the efficiency of the organisms in the manures and in the soil were too slight to be distinctive.

2. A depression in phosphorus-availability followed the fermenting of the untreated horse manure and cow manure, but in the compost a slight increase occurred.

3. The addition of sulfur to the manures resulted in greater solubility of the phosphorus than was found in the untreated manures.

4. Composting floats with manure not only resulted in no increased availability of the phosphorus but in every case caused a noticeable depression which was not overcome at the end of 15 weeks' fermentation.

5. Composting floats with manure and sulfur caused a remarkable increase in the production of available phosphorus which became greater with longer continued fermentation up to 15 weeks. This increase was greater where the sulfur and floats were intimately mixed with the manure than where they were added to the manure in layers.

6. Experiments are necessary to ascertain the best amount of phosphate to mix with sulfur and manure to secure the highest percentage of availability.

7. Further tests of this method of producing available phosphorus may prove it to be of considerable practical value.

REFERENCES

(1) Ames, J. W., and Gaither, E. W. 1912 Barnyard manure: production, composition, conservation, reinforcement and value. Ohio Agr. Exp. Sta. Bul. 246.

(2) Brown, P. E., and Kellogg, E. H. 1914 Sulfofication in soils. Iowa Agr. Exp. Sta. Research Bul. 18, p. 49–111.

(3) Egorov, M. A. 1911 Different kinds of stable manure as sources of phosphoric acid. *In* Zhur. Opuitn. Agron. [Russ. Jour. Expt. Landw.], v. 12, no. 4, p. 498–528. *Abs. in* Exp. Sta. Rec., v. 26, p. 123.

(4) Fraps, G. S. 1909 Active phosphoric acid and its relation to the needs of the soil for phosphoric acid in pot experiments. Tex. Agr. Exp. Sta. Bul. 126.

(5) Lipman, J. G., McLean, H. C., and Lint, H. C. 1916 The oxidation of sulfur in soils as a means of increasing the availability of mineral phosphates. *In* Soil Sci., v. 1, no. 6, p. 533–539.

(6) Lipman, J. G., McLean, H. C., and Lint, H. C. 1916 Sulfur oxidation in soils and its effect on the availability of mineral phosphates. *In* Soil Sci., v. 2, no. 6, p. 499–538.

(7) Tottingham, W. E., and Hoffman, C. 1913 Nature of changes in the solubility and availability of phosphorus in fermenting mixtures. Wis. Agr. Exp. Sta. Research Bul. 29.

TOTAL NITROGEN AND CARBON IN CULTIVATED LAND AND LAND ABANDONED TO GRASS AND WEEDS

A. W. BLAIR AND H. C. McLEAN

New Jersey Agricultural Experiment Station

INTRODUCTION

Received for publication June 29, 1917

A deficiency of nitrogen in the soil so often becomes a limiting factor in crop production that any investigation which has as its object a determination of the cause of losses, or methods of increasing the supply, of this element, is of prime importance.

It is already well known that under continuous cropping nitrogen does disappear rapidly from cultivated soils, and that frequently the supply is not maintained even when fair amounts of nitrogenous fertilizers are applied annually (6). That the amount removed in the crop does not account for the total loss is likewise well known, but beyond the fact that a part of it is found in the drainage waters as nitrates, the information is not very definite.

In this connection Snyder (14) discussing the effect of the continuous growing of wheat on the same land for a period of years says:

> When wheat was grown continuously upon the same soil for eight years, there was a loss of 1700 pounds per acre of nitrogen, about 300 pounds being utilized as plant-food and 1400 pounds lost by the decay of the animal and vegetable matter of the soil and the liberation of the nitrogen as gaseous and soluble compounds. During the eight years of continuous wheat cultivation there was a loss of over 21 per cent of the total nitrogen of the soil, equivalent to an annual loss of 175 pounds per acre in addition to that used as plant-food.

He found about the same loss when oats and barley were grown continuously. The same author in a later publication says: (15)

> The loss of nitrogen from four grain farms in ten years amounted to three to five times more than was removed by the crops. This loss was due to the rapid decay of the humus and the liberation of the nitrogen, which forms an essential part of the humus. When clover was grown, crops rotated, live stock kept and farm manure used, an equilibrium as to the nitrogen content of the soil was maintained, the mineral plant-food was kept in the most available condition and maximum yields were secured.

Alway, who has made an exhaustive study of the loess soils of Nebraska, says (1): "Analyses show a great loss of nitrogen, humus and unhumified organic matter in the case of all fields long under cultivation." In their virgin condition he finds these soils rich in the constituents mentioned.

Under a consideration of the nitrogen problem Russell (11) says:

No element of plant-food is so liable to waste as nitrogen. If a farmer applies potash or phosphoric acid to his land he may reasonably expect to get most of it back again, but when he applies nitrogen he is almost certain to lose a good proportion of it. The sound practice is therefore to keep the nitrogen circulating, to crop it out and replace it, rather than to aim at leaving it in the soil.

Shutt (13) calls attention to the unusually high nitrogen content of some of the soils of Manitoba and Saskatchewan (0.2 per cent to 1.00 per cent) but points to the fact that the system of grain growing now in practice on some of the lands results in a large loss of nitrogen annually.

On the other hand, it has been claimed that land allowed to run wild increases in fertility. In this connection Hall (4) calls attention to the fact that a piece of land at Rothamsted which was allowed to run wild contained, at the end of 20 years, 2200 pounds more of nitrogen than it contained at the beginning of the period. This means an increase of more than 100 pounds per acre annually. Hall thinks this increase may be due to symbiotic and non-symbiotic fixation, absorption of ammonia, rise of nitrates from the lower subsoil, and nitrogen compounds brought down in rain water.

Another (2) writer claims that plants derive much more plant-food from soils than chemical analysis accounts for. He says:

A large amount of incidental plant-food, is evidently conveyed by rain water. It appears probable also that the fertility given by the deposited excreta of small animals, birds, insects and worms and reptiles, and the decay of their bodies upon the ground and also the decay of vegetable matter, dust deposited by the wind, leaves, flowers and seeds and branches, etc., is largely in excess of what has previously been estimated, and in fact it is of as much importance as food obtained from the reserves held by the soil itself. This must be known as the incidental increment and must be taken into full account in all agricultural operations.

Hall (5) in a later publication calls attention to the fact that

with every system of farming a certain position of equilibrium will be reached (viewed over a term of years long enough to smooth out seasonal effects) when the natural recuperative agencies and the additions of fertilizing materials in the manure are balanced by the removals in crops and stock and the inevitable waste.

The higher the level of production, the greater will be the waste, and in consequence, the addition of fertilizer must be doubly increased to maintain the balance.

Schneidewind (12) conducted experiments which gave indication that under ordinary methods of intensive culture with liberal use of manure and fertilizers there was a marked depletion of the nitrogen and potassium supply of the soil. There was a relative increase of the phosphoric acid under such a system. Perotti (10) discussing gain of nitrogen, considers bacteria, molds, algae and legumes; and under loss, volatilization of ammonia and denitrification. Shutt (13), by analyses of virgin and cultivated soils, has called attention to the exhaustion of soils by continuous cropping without manure and has shown by experiment that a soil successively cropped to clover continues to increase in nitrogen under this treatment.

Moores, Hampton and Hunter (9) have shown that land in sod for a number of years, suffered a serious loss of nitrogen during five years' cultivation with a double crop rotation of cowpeas and wheat. In this connection they say:

> The fact, therefore, that the soil content of nitrogen was not even maintained where a leguminous green crop equal to more than a ton per acre of thoroughly cured hay, on the average, not to mention the fallen leaves, stubble and roots, was turned under each year is almost startling and shows the necessity of a superior system of management if anything like high fertility of the soil is to be maintained without recourse to outside supplies of nitrogen, such as would be furnished by nitrogenous fertilizers and commercial feeding stuffs.

In summing up their conclusions they say further:

> By taking the nitrogen removed by the crop into consideration, there was found to be, at the end of five years, (1) where the cowpea crop was turned under, a gain per acre on the unlimed sections of 67 pounds, to be accounted for in sources outside of the 8-inch depth of plowing, but on the limed sections none; (2) where the cowpea crop was removed, a gain per acre of 181 pounds on the unlimed and 177 pounds on the limed, to be accounted for as before.

Swanson (18) states that the soils of Kansas show an average decrease in crop-producing power in spite of the fact that farmers use good seed and improved methods of tillage. Results based on the analysis of cultivated and uncultivated soils in seven representative counties, show that carbon and nitrogen have disappeared from the cultivated to a greater extent than from the uncultivated soils. In round numbers they have lost from one-fifth to two-fifths of their nitrogen and from nearly one-fourth to one-half of the carbon.

Somerville (16) in making a study of the effect of applications of phosphatic manures (notably basic slag) took portions of soil from treated and untreated plots that have been under observation in different sections of England for the past 20 to 30 years and with this soil conducted pot experiments using oats as the first crop. He reports notable increases in yield from the treated soil over the untreated soil. He says:

> While it would appear, that the accumulated fertility is partly due to phosphate residues, it is certainly due in most part to the secondary effects of the phosphates, of which the accumulating of humus, including the accumulation of atmospheric nitrogen, is probably the most important.

In a second article (17) he attributes the accumulated fertility largely to nitrogen stored up by leguminous plants, but believes the increase in non-leguminous humus is not without influence.

In an article on the chemical composition of virgin and cropped Indiana soils, Connor (3) says:

> In spite of the fact that the tendency of nature is to build up and replenish the fertility of the soil, there is no question but that the destructive system of cultivation that has been followed by the farmers of this country has more than counter-balanced nature's tendency to upbuild, and as a consequence the soil has become more or less depleted.

In this connection Connor reports analyses of a number of virgin and cropped soils, and these analyses, he believes, indicate certain changes in the chemical composition of the soil which sixty to eighty years of cropping have brought about. He finds:

> that although most of the soil ingredients have not changed enough to make any great difference in the chemical composition of the virgin and cropped soils, there are some notable exceptions.
>
> The most serious losses from the standpoint of soil fertility are those of nitrogen, which shows a loss of 28 per cent, and the organic matter which shows a loss in the volatile matter of 26 per cent and in the humus of 47 per cent. These losses are without doubt the main reason why our cropped soils are no longer as fertile as they formerly were.

If one may judge by the references cited there seems little room to doubt that under continued cropping soils are rather rapidly depleted of their nitrogen and organic matter, and that there may be an actual loss of nitrogen and carbon even when leguminous crops are turned under and manures applied. With uncultivated soils, on the other hand, the losses are not so great and in some instances there are pronounced gains.

EXPERIMENTAL

One of the objects of this experiment was to study the changes which occur in the vegetation on abandoned land and especially the effect of commercial fertilizers on the appearance or disappearance of certain species of plants on such land. The experiment also includes a study of the composition of the soil on the abandoned land as compared with the composition of soil from adjoining plots which are under a 5-year rotation of corn, oats, wheat and two years of grass (originally two years of oats), and the determination of the percentage of applied nitrogen that is recovered in the crop. The soil is a loam inclining to the gravelly phase, with a sandy loam subsoil. Previous to 1908 this land had been neglected for a number of years. The plots were laid out one-twentieth acre in size, one-half to be under cultivation and the other half to remain uncultivated. Beginning with the corn crop of 1908 the plots received a dressing of ground limestone at the rate of 1 ton per acre and beginning with the second five-year period in the spring of 1913 they received a further application of this material at the rate of 2 tons per acre. The uncultivated halves have received the same fertilizer and lime treatment as the cultivated halves. The plots are arranged in pairs with reference to the fertilizer treatment as indicated in the accompanying diagram.

The nitrogen is supplied in the form of ground fish at the rate of 600 pounds per acre, the phosphoric acid as acid phosphate at the rate of 600 pounds per acre and the potash as muriate of potash at the rate of 300 pounds per acre. These materials have been applied annually in accordance with the plan, except for the oat crop in 1911 when no fertilizers were applied. Also, through an error the nitrogen was omitted from plots 63 and 64 in 1914.

Each year a record is made of the kinds of weeds and grasses found on the uncultivated part of the plots, and the number of such plants recorded or the area which they cover measured. It is thus possible to say whether certain species are disappearing and others taking their places under the different treatments. In the late summer the weeds and grass are cut down on these plots but nothing is removed.

It is not the intention to give in this paper a detailed statement of the crop yields on the cultivated section nor to give a complete record of the vegetation on the uncultivated section (the latter is reserved for a later publication) but rather to compare the nitrogen and carbon content of the soils from the two sections, and, taking into consideration the nitrogen removed by the crops on the cultivated sections, determine whether the net result with reference to this element has been loss or gain. No account has been taken of the carbon in the crop so that a comparison so far as this element is concerned is with reference to the amount in the soil of the two sections, cultivated and uncultivated.

CULTIVATED HALF

57	58	59	60	61	62	63	64
Phos. Acid Potash	Phos. Acid Potash	Nitrogen Potash	Nitrogen Potash	Nitrogen Phos. Acid	Nitrogen Phos. Acid	Nitrogen Phos. Acid Potash	Nitrogen Phos. Acid Potash
57	58	59	60	61	62	63	64

UNCULTIVATED HALF

Unfortunately no samples were collected from these plots when the work was begun.

Table 1 gives the results of nitrogen and carbon determinations made on samples taken from the cultivated and uncultivated sections of plots 57 to 64 in 1913 and also in 1916. In taking the samples 6 borings, to a depth of $6\frac{2}{3}$ inches, were made with a tube cutting a core about 2 inches in diameter, and these cores were made into one sample, dried, passed through a 3-mm. sieve to remove coarse material and finally ground to pass a 0.5 mm. sieve.

Nitrogen determinations were made by the Kjeldahl-Gunning method, five or six determinations being made on each sample.

A study of this table brings out the fact that without exception both nitrogen and carbon are now higher in the uncultivated sections than in the cultivated. The average difference in nitrogen content between the two sections for the

nitrogen-treated plots, was 0.02 per cent in 1913, and 0.0234 per cent in 1916, the former being equivalent to 400 pounds of nitrogen per acre $6\frac{2}{3}$ inches (2,000-000 pounds of soil) and the latter equivalent to 468 pounds. The average difference between the cultivated and uncultivated sections of plots 57 and 58, the plots that receive no nitrogen, was in 1913, 0.0123 per cent, which makes a difference in favor of the uncultivated section of 226 pounds of nitrogen per acre, whereas the difference in 1916 was 0.0258 per cent or 516 pounds per acre.

TABLE 1

Nitrogen and carbon in soil, 1913 and 1916

	TOTAL NITROGEN				TOTAL CARBON			
	1913		1916		1913		1916	
	Cultivated	Uncultivated	Cultivated	Uncultivated	Cultivated	Uncultivated	Cultivated	Uncultivated
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
57	0.0913	0.1054	0.0749	0.1003	1.028	1.320	1.003	1.275
58	0.0787	0.0891	0.0715	0.0977	0.995	1.130	0.995	1.269
Average.....	0.0850	0.0973	0.0732	0.0990	1.012	1.225	0.999	1.272
59	0.0809	0.0949	0.0802	0.0985	1.047	1.265	1.048	1.300
60	0.0913	0.1034	0.0824	0.1063	1.142	1.279	1.086	1.311
61	0.0795	0.1041	0.0841	0.0981	0.972	1.245	0.960	1.231
62	0.0874	0.1106	0.0773	0.1134	1.022	1.459	0.999	1.533
63	0.0806	0.1053	0.0802	0.1067	1.028	1.281	1.017	1.440
64	0.0876	0.1108	0.0856	0.1072	1.042	1.364	1.106	1.228
Average.....	0.0846	0.1049	0.0816	0.1050	1.042	1.316	1.036	1.341

This accords well with the view that liberal applications of the minerals favor the appearance of volunteer leguminous plants on abandoned land and also the fixation of atmospheric nitrogen by non-symbiotic bacteria, and no doubt accounts for the fact that on the uncultivated sections of these plots the nitrogen supply is fairly well maintained. On the other hand, the cultivated sections are gradually being depleted of their supply of nitrogen, the volunteer leguminous plants not being permitted to come in to restore the losses.

Taking an average of all the nitrogen-treated plots, the cultivated portions show slightly less nitrogen in 1916 than in 1913, in spite of the fact that they have received fair annual applications of nitrogenous fertilizers. For the uncultivated sections the average is essentially the same in 1916 as in 1913, that is, the gain during the three years has not been sufficient to make an appreciable difference in the analyses. It is evident that the total carbon is being gradually decreased on the cultivated sections. This is shown by an average percentage of 1.042 in 1913 and 1.036 in 1916. It is further emphasized,

however, by the fact that determinations made on samples collected in 1909 from nearby plots, where the soil is the same as the soil of the plots under consideration, show 1.21 per cent of total carbon (6). From this it would appear that the cultivated plots have lost nearly 0.2 per cent of carbon during the period 1909 to 1916. On the other hand, the carbon is undoubtedly

TABLE 2

Yields of nitrogen in a five-year rotation, 1908 to 1916 inclusive

(Calculated on the acre basis)

	CORN 1908	OATS 1909	WHEAT 1910	OATS 1911	TIMOTHY 1912	TOTAL NITROGEN FOR FIRST FIVE YEARS	CORN 1913	OATS 1914	WHEAT 1915	TIMOTHY 1916	TOTAL NITROGEN 1913–1916 INCLUSIVE	TOTAL NITROGEN 1908–1916 INCLUSIVE
57	52.76	19.44	25.48	17.80	5.64	121.12	30.44	14.76	18.60	18.55	82.35	203.47
58	45.60	17.28	28.12	18.16	2.16	111.32	28.64	12.14	19.20	17.49	77.47	188.79
Average						116.22					79.91	196.13
59	74.40	28.48	47.80	21.20	5.28	177.16	50.44	23.04	30.00	23.71	127.19	304.35
60	76.40	33.52	55.88	33.16	6.76	205.72	53.68	36.42	37.44	24.83	152.37	358.09
Average						191.44					139.78	331.22
Average increase over check						75.22					59.87	135.09
61	90.28	31.20	52.12	34.52	7.12	215.24	36.88	23.42	38.52	28.42	127.24	342.48
62	41.12*	33.76	46.72	30.00	6.44	158.04	51.40	25.92	32.38	27.14	136.84	294.88
Average						186.64					132.04	318.68
Average increase over check						70.42					52.13	122.55
63	77.04	30.24	51.92	33.84	7.00	200.04	58.40	22.48	29.72	29.01	139.61	339.65
64	74.36	28.88	53.44	36.12	9.84	202.64	54.64	21.22	35.42	26.26	137.54	340.18
Average						201.34					138.58	339.92
Average increase over check						85.12					58.67	143.79
General Average	72.27	31.01	51.31	31.47	7.07	193.14	50.91	25.41	33.91	24.90	136.80	329.94
Average increase over check						76.92					56.89	133.81

* Very low yield of stalks for some reason.

increasing in the uncultivated plots, as is shown by an average of 1.316 per cent in 1913 and an average of 1.341 per cent in 1916, and by the further fact, already mentioned, that the samples collected in 1909 from nearby plots show only 1.21 per cent of carbon. Thus it would appear that during the period 1909 to 1916 the carbon content of the uncultivated soils has increased by about 0.13 per cent, which would be equivalent to slightly more than $1\frac{1}{4}$ tons

of carbon per acre 6⅞ inches. This is as one might expect, since each year there has been a fair growth of weeds and grasses on these plots and nothing has been removed.

Table 2 shows the amount of nitrogen removed by the crops on the cultivated portion of the plots for the years 1908 to 1916 inclusive, and the average amount for each crop on the eight plots. It will be observed that the corn crop of 1908 yielded the largest amount of nitrogen. This is followed by the corn crop of 1913 and the wheat crop of 1910, both of which furnished approximately 20 pounds less of nitrogen than the corn crop of 1908. The lowest yield was with the timothy of 1912. This is accounted for in part at least by the small crop of that year. With only two exceptions there was less nitrogen recovered from plots 57 and 58—the two that receive no nitrogen—than from those that receive an annual application of nitrogen. The average yield from plots 57 and 58 may be taken as the check, and if this is deducted from the average yields from the plots that receive nitrogenous fertilizers, the remainder may be taken as the amount of the applied nitrogen that was recovered in the crop. The nitrogen-treated plots have received the dried fish at the rate of 600 pounds per acre, but on account of the omission in 1911 the total for the five years was 2400 pounds instead of 3000 pounds. This, on the basis of 8 per cent nitrogen for the fish, would mean a total of 192 pounds of nitrogen per acre for the first five years and also 192 pounds for the last four years, excepting plots 63 and 64 which, on account of the omission in 1914, received only 144 pounds, thus making the average for the four years 176 pounds instead of 192 pounds. This gives a total for the nine years of 368 pounds.

These figures divided into the increase over the check for the respective periods, with the proper pointing off, give the percentages of nitrogen recovered in the crop.

The results calculated for the different treatments are as follows:

PLOTS	FIRST PERIOD, FIVE YEARS	SECOND PERIOD, FOUR YEARS
59.60	39.18	31.18
61.62	36.67	27.15
63.64	44.33	40.74
Average.....	40.06	33.02

Stated in another way the average increase over the check is, for the nine years, 133.81 pounds of nitrogen per acre (bottom figure in last column of table 2) and the total amount of nitrogen applied per acre during that time was 368 pounds. From these figures it is found that there was an average annual recovery for the nine years of 36.36 per cent of the applied nitrogen; that is, a recovery of only a little more than one-third. The highest average recovery for 9 years is from plots 63 and 64 which receive the complete fer-

tilizer, and the next highest from lots 59 and 60 which receive nitrogen and potash.

The average recovery for the first period is a little higher than for the second period. These figures correspond quite closely with recoveries obtained from dried blood in cylinder experiments previously reported (7) and also for the most part with recoveries from fish scrap used in field experiments (6) where the rotation was the same as the one here considered. Slightly higher recoveries were obtained where fish was used as a source of nitrogen in pot experiments (8). The average total recovery from plots 59 to 64 for the nine years is 329.94 pounds (acre basis) while the total amount applied to each plot during the same period was 368 pounds if 8 per cent is taken as the analysis of the fish. During this period the crops on plots 57 and 58, without commercial nitrogen, were able to take from the soil an average of nearly 200 pounds of nitrogen per acre.

From the results it seems quite clear that nitrogen is the limiting factor in crop production on this soil, otherwise plot 60, where no potash has been applied, and plot 61, where no phosphoric acid has been applied, would hardly have given yields of nitrogen in excess of plots 63 and 64 where all three constituents were used. It is true that the averages for 59 and 60 and for 61 and 62 are not quite as high as the average for 63 and 64, but the difference is so small that one could hardly say that the yield was limited by a lack of potash in the one case or of phosphoric acid in the other.

That nearly two-thirds of the applied nitrogen should be unaccounted for is discouraging and does not plead very strongly for the use of commercial nitrogenous materials of an organic nature, if those of mineral origin are available.

SUMMARY

It is here pointed out that the average nitrogen content of land which was allowed to run wild from 1908 to 1916, and which during that period received annual applications of dried fish amounting to 600 pounds per acre, was essentially the same in 1916 as in 1913. (No samples were collected previous to 1913.)

The carbon content of this same land was increased slightly during the period 1913 to 1916.

The average nitrogen content of adjoining cultivated plots, under a 5-year rotation, was 0.02 per cent less in 1913, and 0.023 per cent less in 1916, than the nitrogen content of the corresponding plots that were allowed to run wild.

The average nitrogen content of the cultivated plots was slightly less in 1916 than in 1913.

The average carbon content of the cultivated plots was approximately 0.27 per cent less in 1913 and 0.30 per cent less in 1916 than the average carbon content of the corresponding plots allowed to run wild.

The average carbon content of the cultivated soils was slightly less in 1916 than 1913.

The two cultivated plots which received no nitrogen (the check plots) yielded, in the crops from these plots, an average total of 196.13 pounds of nitrogen for the nine years.

The six nitrogen-treated plots yielded, during the same period, an average total of 329.94 pounds of nitrogen in the crops from these plots.

There was recovered from the six nitrogen-treated plots for the nine-year period, an average of 36.36 per cent of the nitrogen that was applied.

The percentage of nitrogen and carbon in the cultivated soils is decreasing, even where dried fish is applied at the rate of 600 pounds per acre annually.

The percentage of nitrogen in the soils allowed to run wild, and which have received annual applications of nitrogen, appears to run about constant, but the percentage of carbon is increasing slightly.

Much volunteer white clover is appearing on the two plots which receive minerals but no nitrogen.

LITERATURE CITED

(1) ALWAY, F. J. 1909 Changes in the composition of the Loess soils of Nebraska caused by cultivation. Neb. Agr. Exp. Sta. Bul. 111.

(2) Bulletin of Miscellaneous Information. Trinidad Bot. Dept. 1910, No. 27, p. 325–327.

(3) CONNOR, S. D. 1914 The chemical composition of virgin and cropped Indiana Soils *In* Proc. Ind. Acad. Sci., 1914, p. 359–363.

(4) HALL, A. D. 1905 On the accumulation of fertility by land allowed to run wild. *In* Jour. Agr. Sci., vol. 1, p. 241–249.

(5) HALL, A. D. 1910 The conservation of the fertility of the soil. *In* Jour. Bd. Agr. (London), vol. 17, no. 2, p. 114–123.

(6) LIPMAN, J. G., AND BLAIR, A. W. 1913 Field experiments on the availability of nitrogenous fertilizers. N. J. Agr. Exp. Sta. Bul. 260.

(7) LIPMAN, J. G., AND BLAIR, A. W. 1916 Investigations relative to the use of nitrogenous plant foods 1898–1912. N. J. Agr. Exp. Sta. Bul. 288.

(8) LIPMAN, J. G., AND BLAIR, A. W. 1911 The availability of nitrogen in dried blood, tankage, dried fish and ammoniates. *In* N. J. Agr. Exp. Sta. 32nd Ann. Rpt., p. 232–235.

(9) MOOERS, C. A., HAMPTON, H. H., AND HUNTER, W. K. 1912 The effect of liming and green manuring on the soil content of nitrogen and humus. Tenn. Agr. Exp. Sta. Bul. 96.

(10) PEROTTI, R. 1909 The nitrogen problem. *In* Bol. Quind. Soc. Agr. Itl., vol. 13, no. 23, p. 1186–1196; vol. 14, No. 2, p. 48–62; no. 3, p. 84–100.

(11) RUSSELL, E. J. 1908 The nitrogen problem in crop production. *In* Jour. Roy. Agr. Soc. (England), vol. 69, p. 104–114.

(12) SCHNEIDEWIND. 1910 Soil robbery and fertilizing in the light of recent experiments. *In* Landw. Wchnschr. Sachsen, Bd. 12, No. 12, p. 93. *Abs. in* Chem. Ztg., Bd. 34, No. 62, Repert., p. 241.

(13) SHUTT, F. T. 1905 The nitrogen enrichment of soils through the growth of legumes. *In* Canada Exp. Farms Rpts. 1905, p. 127–130; and 1911 The nitrogen enrichment of soils through the growth of clover. *In* Canada Exp. Farms. Rpts. 1911, p. 173.

(14) SNYDER, HARRY 1901 Influence of wheat farming upon soil fertility. Minn. Agr. Exp. Sta. Bul. 70.

(15) SNYDER, HARRY 1906 Soil investigations. Fertility tests with wheat and corn. Minn. Agr. Exp. Sta. Bul. 94.

(16) SOMERVILLE, W. 1914 Accumulated fertility in grass land in consequence of phosphatic manuring. *In* Jour. Bd. Agr. (London), vol. 21, no. 6, p. 481–492.

(17) SOMERVILLE, W. 1916 Accumulated fertility in grass land in consequence of phosphatic manuring. II. *In* Jour. Bd. Agr. (London), vol. 22, no. 12, p. 1201–1209.

(18) SWANSON, C. O. 1915 The loss of nitrogen and organic matter in cultivated Kansas soils and the effect of this loss on the crop-producing power of the soil. *In* Jour. Indus. Engin. Chem., vol. 7, no. 6, p. 529–532.

THE DETERMINATION OF SOIL PHOSPHORUS[1]

CLAYTON O. ROST

Agricultural Experiment Station, University of Minnesota

Received for publication June 21, 1917

INTRODUCTION

Robinson (10) has recently reported a critical comparison of three methods for the determination of soil phosphorus, namely: fusion with alkali carbonates, the Washington method, in which the soil is evaporated to dryness with hydrofluoric acid previous to ignition, and the Fischer method, which is characterized by an ignition between two evaporations with aqua regia. He concluded that all three of these give accurate results, provided that the first two be modified so as to get rid of the organic matter without an accompanying loss of phosphorus. He implies that the failure to recover the full amount of phosphorus from soils by the Washington method is due to the volatilization of a part of it during ignition, which he states may be avoided by previously evaporating the samples with nitric acid, in order to dissolve "enough bases to hold the phosphoric acid during the ignition," and then carrying out the latter operation "in such a manner that there is no glowing." Using a soil containing 0.04 per cent of phosphoric acid and 0.29 per cent of organic matter he added a known amount of phosphoric acid and 0.5 gm. of sugar, hastily ignited the mixture to glowing and found "an apparent loss of from 30 to 11 per cent of the phosphorus present."

In the fusion method, preceded, in the case of soils high in organic matter, by evaporation with magnesium nitrate solution or with nitric acid and subsequent ignition, he mentions (10, p. 149) that there is "one inherent error as previously pointed out, i.e., the solubility of small amounts of ammonium phosphomolybdate in aqueous solutions of sodium nitrate" and that this difficulty can be overcome by precipitating the sesquioxides, which carry down with them the phosphoric acid, redissolving these, and again precipitating the phosphorus as ammonium phosphomolybdate.

The work of the author reported in this paper does not confirm the statement of Robinson (10, p. 148, foot-note 5) regarding the liability of serious loss of ammonium phosphomolybdate in the course of the ordinary deter-

[1] Published with the approval of the Director as Paper No. 73, of the Journal Series of the Minnesota Agricultural Experiment Station.

mination by fusion with alkali carbonate. Cain and Hostetter[2] (2, p. 251) in reporting the solubility of the yellow ammonium phosphomolybdate in the presence of vanadium salts did not include sodium nitrate in the list of reagents tested. They found ammonium phosphomolydbate, even in the presence of vanadium salts, to be far less soluble in solutions of nitrates than in neutral ammonium molybdate. Gortner and Shaw (4) have shown that vanadium, in the amounts ordinarily present in the soil, does not interfere with the determination of the soil phosphorus.

In the Fischer (3) method the author finds there is liable to be a large amount of phosphoric acid left in the insoluble residue, thus making the method appear as unsuitable for the determination of total phosphoric acid as the methods by extraction with strong nitric or hydrochloric acid.

Applying the ordinary Washington (11, p. 162) method to soils the author finds that it is liable to give results much too low, but that this is not due to volatilization of phosphoric acid during ignition and is not lessened by previous evaporation with either magnesium nitrate solution or nitric acid, while the elimination of the organic matter by ignition without glowing, as proposed by Robinson (10, p. 149) is not feasible, especially in the case of soils high in organic matter.

EXPERIMENTAL

Soils used

Four samples, two of mineral soil and two of peat (table 1), were used in this study. Both of the first two, A, a Carrington silt loam and B, a Fargo silt loam, from Rice County, Minnesota, were rich in organic matter, while A contained a much larger proportion of coarse particles and accordingly was apt to carry a larger proportion of its phosphoric acid as apatite inclusions in quartz grains. Of the two peat soils, C was low in lime, while the other, D, carried a moderate amount. Both contained about 90 per cent of organic matter.

All the samples were ground in an agate mortar so as to pass a silk bolting cloth of 0.25 mm. mesh. Blank determinations on the reagents, made parallel with those on the soils, were exposed to exacctly the same chances of contamination from outside sources as the latter. In all cases the amounts found in the blanks have been deducted from the percentages reported.

[2] Robinson suggests that the reason Fischer found slightly higher quantities of phosphoric acid by his method than by the fusion method is "probably due to the difficulty of precipitating small amounts of ammonium phosphomolybdate in the presence of much $NaNO_3$ in the fusion method, since Cain and Hostetter (Jour. Soc. Chem. Indus., 4 (1912), 250) have shown that aqueous solutions of $NaNO_3$ have a strong solvent effect on the phosphomolybdate when vanadium is present." The reference proved to be other than the one cited, doubtless Jour. Indus. Engin. Chem., 4 (1912), 250, but, in this article, Cain and Hostetter do not report data to corroborate the above statement.

TABLE 1

Composition of soils used

SOIL	VOLATILE MATTER	NON-VOLATILE MATTER	CaO	NITROGEN	ORGANIC CARBON
	per cent	*per cent*	*per cent*	*per cent*	*per cent*
A.....	12.11	87.89		0.384	5.38
B.....	21.10	78.90		0.836	9.95
C.....	90.59	9.41	0.63	2.00	48.95
D.....	89.06	10.94	1.86	2.47	48.47

Fusion method

Soils A and B were analyzed by fusion with sodium carbonate, after ignition alone as well as after previous evaporation with magnesium nitrate. In the case of the former treatment the phosphoric acid was determined both

TABLE 2

Phosphoric acid as found by the different modifications of the fusion method

SOIL	DETERMINATION	IN NITRIC ACID EXTRACT	IN FILTRATE FROM YELLOW PRECIPITATE	IN SEPARATED SILICA	TOTAL AMOUNT RECOVERED
1. Fusion without evaporation with magnesium nitrate: Sesquioxides not precipitated					
		per cent	*per cent*	*per cent*	*per cent*
A.....	1	0.236	0	0.013	0.249
	2	0.236	0	0.006	0.242
	Average.....	0.236	0	0.009	0.245
B.....	1	0.319	0	0.019	0.338
	2	0.325	0	0.006	0.331
	Average.....	0.322	0	0.012	0.334
2. Fusion without evaporation with magnesium nitrate: Sesquioxides precipitated					
A.....	1	0.242	0	0.000	0.242
	2	0.248	0	0.000	0.248
	Average.....	0.245	0	0.000	0.245
B.....	1	0.325	0	0.012	0.337
	2	0.331	0	0.006	0.337
	Average.....	0.328	0	0.009	0.337
3. Fusion after evaporation with magnesium nitrate: Sesquioxides not precipitated					
A.....	1	0.229	0	0.013	0.242
	2	0.236	0	0.006	0.242
	Average.....	0.233	0	0.009	0.242
B.....	1	0.331	0	0.006	0.337
	2	0.338	0	0.000	0.338
	Average.....	0.334	0	0.003	0.337

with and without the precipitation of the sesquioxides. In the case of each analysis the separated silica was evaporated with hydrofluoric acid and the phosphoric acid so obtained determined separately. In all the analyses the filtrate from the yellow precipitate was rendered alkaline with ammonia, the precipitate filtered off, redissolved and the phosphorus determined in this. The data are reported in table 2. The evaporation with magnesium nitrate was accomplished by dissolving 1 gm. of the salt in a few cubic centimeters of water and pouring this over the soil, after which it was evaporated to dryness and carefully ignited.

It is to be seen that only a very small amount of phosphoric acid was found in the separated silica and no advantage was gained from treatment with magnesium nitrate previous to ignition, or by precipitation of the sesquioxides to eliminate the excess of sodium salts.

Fischer method

This, which is a modification of the methods by acid extraction and designed to recover practically the whole of the phosphoric acid in soils, is characterized by two treatments with aqua regia. It is briefly as follows:

> Five to ten gm. of dry soil and 50 cc. of aqua regia are digested on the steam bath in a covered silica dish until effervescence, if any, ceases, after which the watch glass is removed and the contents are evaporated to dryness and ignited until the residue turns brown. The contents are again evaporated to dryness with 50 cc. of aqua regia and the residue treated with concentrated nitric acid and evaporated to dryness to the disappearance of the hydrochloric acid. The residue is finally taken up with dilute nitric acid, filtered and the phosphorus determined in the filtrate.

To test the completeness of extraction by his method, Fischer (3, p. 546) used 4 soils varying in phosphoric acid from 0.14 to 0.47 per cent and found in the residues, which were fused with sodium carbonate, only from 0.004 to 0.009 per cent, a negligible quantity. He makes no mention of heating the residue after evaporation with nitric acid in order to dehydrate the silica. Without such a heating filtration is very difficult. The author, in testing this method, has, like Robinson (10, p. 148), heated the mass until it was brown and then extracted it with nitric acid. It is much better to heat the dish by carefully turning it in an open flame than by using a hot plate or sand bath, thereby avoiding the formation of compounds of iron and aluminum insoluble in nitric acid.

Soils A and B were analyzed by this method, the residue being fused with sodium carbonate. In the case of B the amount of phosphoric acid remaining in the residue in four determinations fell within the limits found by Fischer and in three others it varied from 0.013 to 0.019 per cent, while in each of six determinations with A the amount in the residue lay between the limits of 0.019 and 0.051 per cent, or from 8 to 20 per cent of the total amount present, the latter being far from a negligible quantity.

Suspecting that the large amount of phosphoric acid in the residues might be due to an over-heating after the final evaporation with nitric acid, the product thus obtained was heated in an air bath at 150°C. for 2 hours, and also at 110°C. for 1 hour. The data (table 3, parts 1 and 2) show that nothing

TABLE 3

Phosphoric acid as found by Fischer's method

SOIL	DETERMINATION	IN NITRIC ACID EXTRACT	IN FILTRATE FROM YELLOW PRECIPITATE	IN RESIDUE	TOTAL AMOUNT RECOVERED
	1. Dish heated over open flame				
		per cent	*per cent*	*per cent*	*per cent*
A	1	0.211	0	0.025	0.236
	2	0.217	0	0.019	0.236
	3	0.223	0	0.025	0.248
	3	0.185	0	0.051	0.236
	5	0.217	0	0.025	0.242
	6	0.213	0	0.038	0.251
	Average	0.211	0	0.038	0.241
B	1	0.325	0	0.000	0.325
	2	0.331	0	0.000	0.331
	3	0.331	0	0.000	0.331
	4	0.319	0	0.000	0.325
	5	0.319	0	0.013	0.332
	6	0.319	0	0.019	0.338
	7	0.306	0	0.019	0.325
	Average	0.321	0	0.008	0.329
	2. Dish dried in oven for 2 hours at 150°C.				
A	1	0.204	0	0.045	0.249
	2	0.217	0	0.019	0.236
	Average	0.211	0	0.032	0.243
B	1	0.312	0	0.019	0.331
	2	0.306	0	0.032	0.338
	Average	0.309	0	0.025	0.334
	3. Dish dried in oven for 1 hour at 110°C.				
A	1	0.217	0	0.032	0.249
B	1	0.306	0	0.026	0.332

is gained by heating at a lower temperature, while this has the disadvantage of consuming more time. From the above it appears that while with some soils the method may give, at least under certain conditions, satisfactory results, with others it is likely to give results much too low.

Washington method

The soils A and B were analyzed by this method (11, p. 162), modified to the extent that after the second evaporation with nitric acid the residue, instead of being heated until it became brown, was ignited at a dull red heat. This was necessary in order to get rid of the organic matter. The method when applied to rocks, for which it was designed, does not need any such modification. The residue from the extraction with hydrofluoric and nitric acids was fused, as Hillebrand (7, p. 144) suggests, with sodium carbonate, the melt

TABLE 4

Phosphoric acid as found by Washington's method

DETERMINATION	IN NITRIC ACID EXTRACT	IN FILTRATE FROM YELLOW PRECIPITATE	IN RESIDUE	TOTAL AMOUNT RECOVERED
		Soil A		
	per cent	*per cent*	*per cent*	*per cent*
1	0.197	0	0.061	0.258
2	0.191	0	0.061	0.252
3	0.191	0	0.064	0.255
4	0.197	0	0.051	0.246
5	0.178	0	0.064	0.242
6	0.191	0	0.064	0.255
7	0.185	0	0.057	0.242
8	0.191	0	0.045	0.236
9	0.191	0	0.057	0.248
Average.....	0.190	0	0.058	0.248
		Soil B		
1	0.286	0	0.045	0.331
2	0.331	0	0.000	0.331
3	0.306	0	0.032	0.338
4	0.306	0	0.025	0.335
5	0.306	0	0.045	0.351
6	0.293	0	0.038	0.331
Average.....	0.303	0	0.031	0.336

dissolved and the resulting solution evaporated to dryness twice with nitric acid, the residue taken up with nitric acid and the phosphorus determined in the solution.

The data in table 4 shows that an appreciable amount of phosphoric acid remained in the residue in 14 out of 15 determinations, varying with A from 2 to 25 per cent of the total amount and with B amounting to about 10 per cent.

The amount from the hydrofluoric acid extract and the residue is, within the limits of experimental error, equal to that found by the fusion (table 2) and modified Fischer methods (table 3). Accordingly, the low percentages

of phosphorus that have been found by this method are to be attributed not to volatilization during ignition but to the incompleteness of the extraction by nitric acid.

Both soils were also analyzed by Robinson's modification of the Washington method, in which the soil is evaporated with nitric acid previous to ignition, and any glowing in the latter operation is avoided. From 50 to 65 per cent was thus recovered (column 4 in table 5).

The residues were fused with sodium carbonate and otherwise treated as described in the preceding paragraph and about 20 per cent of the total phosphoric acid in the case of sample A and from 17 to 38 per cent in that of B was obtained (column 6, table 5), leaving still a deficit of 12 to 20 per cent of the total. Since the filtrate from the ammonium phosphomolybdate was strongly colored by organic matter left behind by the low temperature of ignition, it was thought this might still contain phosphorus. This was digested with aqua regia on the sand bath until the organic matter was en-

TABLE 5

Phosphoric acid as found by Robinson's modification of Washington's method

SOIL	DETERMINATION	IN NITRIC ACID EXTRACT		IN FILTRATE FROM YELLOW PRECIPITATE	IN RESIDUE	TOTAL AMOUNT RECOVERED
		First ignition	Second ignition			
		per cent	*per cent*	*per cent*	*per cent*	*per cent*
A...	1	0.185	0.147	0.051	0.057	0.255
	2	0.172	0.147	0.051	0.051	0.249
	Average....	0.178	0.147	0.051	0.054	0.252
B...	1	0.185	0.159	0.045	0.127	0.331
	2	0.299	0.217	0.057	0.057	0.331
	Average....	0.242	0.188	0.051	0.092	0.331

tirely destroyed, after which it was made alkaline with ammonia, the sesquioxides filtered off, dissolved in nitric acid and the phosphorus reprecipitated with ammonium molybdate and determined as usual. The additional quantity thus removed accounts for the total amount (column 5, table 5), The filtrate from the yellow precipitate was tested for phosphorus for every method tried and the present instance was the only one in which any was found.

Both the extract of the ignition product with nitric acid and the filtrate from the first precipitation of ammonium phosphomolybdate were colored, more strongly so with B than with A, while the filtrate from the second precipitation of ammonium phosphomolybdate, that obtained by dissolving the precipitated sesquioxides, was colorless. The first of the two yellow precipitates was dark-colored and this when dissolved in ammonia previous to the addition of magnesium mixture yielded a solution which was dark-colored, resembling the ammonia extract from a soil low in humus (*matière noire* of

Grandeau). The magnesium ammonium phosphate precipitated from this solution was gray as though containing some of the so-called magnesium humate. To decide whether magnesium other than that in the magnesium ammonium phosphate was contained in this precipitate the latter, after being filtered, washed, dried, ignited and weighed, was dissolved in nitric acid and reprecipitated with magnesium mixture. The phosphoric acid calculated from the weight of the resulting magnesium pyrophosphate was much less than that first obtained (columns 3 and 4, table 5).

The phosphoric acid was also determined on the samples A and B by this modification of the Washington method with the exception that after the first extraction with nitric acid they were ignited at a higher temperature, a *very dull red*, and then treated as Robinson directs, and as described above. The data are reported in table 6.

TABLE 6

Phosphoric acid as found by Robinson's modification of Washington's method; Samples ignited to a very dull red

SOIL	DETERMINATION	IN NITRIC ACID EXTRACT		IN FILTRATE FROM YELLOW PRECIPITATE	IN RESIDUE	TOTAL AMOUNT RECOVERED
		After first ignition	After second ignition			
		per cent	*per cent*	*per cent*	*per cent*	*per cent*
A..	1	0.229	0.185	0	0.064	0.249
	2	0.212	0.172	0	0.064	0.236
	Average....	0.220	0.179	0	0.064	0.243
B...	1	0.299	0.261	0	0.083	0.344
	2	0.299	0.274	0		
	Average....	0.299	0.267	0		

In no case was the organic matter entirely oxidized by heating to this temperature, although its elimination was undoubtedly more complete in the portions of the sample which were in contact with the dish. In such parts the heat may have been sufficient not only to oxidize the organic matter, but also to produce undesirable changes, while in adjacent parts the oxidation would still be incomplete. The solutions obtained by extracting the ignition product with nitric acid were all colored, although those from A were only slightly so. The filtrates from the ammonium phosphomolybdate were slightly colored but contained no phosphoric acid.

The data in tables 5 and 6 indicate that with soils high in organic matter the magnesium pyrophosphate obtained by Robinson's modification of Washington's method contains a considerable amount of magnesium oxide. Furthermore, a large part of the phosphoric acid may not be precipitated by the ammonium molybdate, probably due to its presence in organic compounds which in turn are due to incomplete oxidation at the low temperature of ignition necessary to avoid all glowing. Further, Robinson's modification of

this method does not appear in any way to affect the amount of phosphorus in the residue from the hydrofluoric acid extraction. It is of interest to note that in the case where the samples were ignited to a very dull red the errors of the method are nearly compensating (columns 3 and 7, table 4). It would also appear that Robinson's modification is far less reliable for soils than Washington's original method modified simply to the extent of igniting the soil to dull redness after the third evaporation with nitric acid.

As it may be suspected that the ignition at a temperature below glowing was faulty, a brief description of this operation as practised by the author

TABLE 7

Phosphoric acid in peat soils as found after ignition both with and without previous evaporation with magnesium nitrate solution

SOIL	DETERMINATION	IN NITRIC ACID EXTRACT	IN FILTRATE FROM YELLOW PRECIPITATE	IN RESIDUE	TOTAL AMOUNT RECOVERED
		1. Without previous treatment			
		per cent	*per cent*	*per cent*	*per cent*
C.....	1	0.242	0	0.013	0.255
	2	0.242	0	0.013	0.255
	Average.....	0.242	0	0.013	0.255
D.....	1	0.289	0	0.006	0.295
	2	0.283	0	0.013	0.296
	Average.....	0.286	0	0.009	0.295
		2. Evaporated with magnesium nitrate solution			
C.....	1	0.242	0	0.013	0.255
	2	0.229	0	0.013	0.242
	Average.....	0.235	0	0.013	0.248
D.....	1	0.293	0	0.006	0.299
	2	0.280	0	0.019	0.299
	3	0.280	0	0.000	0.299
	Average.....	0.291	0	0.008	0.299

appears desirable. The ignition was carried out in a somewhat darkened part of the room and, as a further precaution, the dish was shaded with a large piece of cardboard. Held by means of a pair of platinum-tipped tongs the dish was turned round above a Bunsen flame burning at approximately half its capacity so that every part was exposed to the heat As soon as any portion showed the faintest indication of reddening the dish was turned so as to allow the heat to strike a cooler part.

From the above there appears no good reason to attribute any incomplete recovery of phosphorus to loss by volatilization during ignition. Additional evidence is presented in table 7 showing the amount of phosphoric acid in

two peat soils recovered both by the ordinary ignition to redness without any previous treatment and by a similar ignition after evaporation with magnesium nitrate solution. As both samples carried 90 per cent of organic matter any loss of phosphorus due to lack of bases should have been expected in C which carried so little lime that unless previously treated with ground limestone or some other form of agricultural lime it has regularly proved sterile to all ordinary crops, except redtop (*Agrostis alba*). In C as well as in D no increase in the amount of phosphoric acid recovered results from the treatment with magnesium nitrate.

As further evidence of this same fact sample A was mixed with 0.5 gm. of sugar and ignited, not *hastily* but carefully, as in the ordinary determination, and the phosphoric acid determined by the proposed modification (see below) of Washington's method. The data are shown in table 8. There appears no justification for a hasty ignition especially when there is so great an opportunity for mechanical loss along with the escape of the water of

TABLE 8

Phosphoric acid as found in Sample A after ignition with sugar

SOIL	DETERMINATION	IN NITRIC ACID EXTRACT	IN FILTRATE FROM YELLOW PRECIPITATE	IN RESIDUE	TOTAL AMOUNT
		per cent	*per cent*	*per cent*	*per cent*
A.....	1	0.248	0	0.006	0.254
	2	0.248	0	0.006	0.254
	Average.....	0.248	0	0.006	0.254

decomposition from the sugar. In case a solution containing phosphorus had been added the chance for loss in this manner would have been still greater.

Author's modification of Washington method

The author has found that Washington's method may be modified slightly so as to provide for the elimination of the organic matter of soils and the complete extraction of the phosphorus by means of hydrofluoric acid and nitric acid without making it less satisfactory for soils than it has proven for rocks. The only place where it would not be suitable would be where platinum ware is not available.

The dried soil is, as in the methods of Grandeau (5, p. 267) and Hilgard (6, p. 20), ignited to dull redness, preferably in a muffle, and then treated according to Washington's directions up to the last evaporation with nitric acid. Then the residue in the platinum dish is heated in an air bath at 110°C. for 1 or 2 hours in order to dehydrate the silica, the greater length of time being preferable since a more complete dehydration is obtained and filtration is rendered easier. It may even be satisfactorily heated over a naked flame of the Bunsen burner, but this is not to be recommended, as there is a much

greater danger of overheating than by drying the sample in an oven. Filtration after dehydration of the silica by the latter method, however, is considerably slower than after dehydration above the direct flame. Using twelve samples dried in an air bath for 2 hours at 110°C. the time for filtration and washing was determined and found to be 2 hours.

TABLE 9

Phosphoric acid as found by the author's modification of Washington's method

SOIL	DETERMINATION	IN NITRIC ACID EXTRACT	IN FILTRATE FROM YELLOW PRECIPITATE	IN RESIDUE	TOTAL AMOUNT RECOVERED
1. Heated in an air bath 1 hour at 110° C.					
		per cent	*per cent*	*per cent*	*per cent*
A.....	1	0.242	0	0	0.242
	2	0.248	0	0	0.248
	Average.....	0.245	0	0	0.245
B.....	1	0.331	0	0	0.331
	2	0.331	0	0	0.331
	Average.....	0.331	0	0	0.331
2. Heated 1 to 2 hours in an air bath at 150°C.					
A.....	1	0.204	0	0.045	0.249
	2	0.217	0	0.019	0.236
	Average.....	0.211	0	0.032	0.243
B.....	1	0.312	0	0.019	0.331
	2	0.306	0	0.032	0.338
	Average.....	0.309	0	0.025	0.334
3. Heated above an open flame					
A.....	1	0.255	0	0.000	0.255
	2	0.217	0	0.025	0.242
	Average.....	0.236	0	0.012	0.248
B.....	1	0.338	0	0.000	0.338
	2	0.344	0	0.000	0.344
	Average.....	0.341	0	0.000	0.341

The formation of red oxide insoluble in nitric acid is evidence of overheating. In case such a red oxide is formed a few cubic centimeters of nitric acid and hydrofluoric acid are added to the platinum dish containing the sample, the contents evaporated to dryness and the evaporation repeated twice with nitric acid to decompose the fluorides, after which it is treated as a new sample.

The method as finally developed is briefly as follows:

One gram of dry soil is weighed out in a platinum dish of appropriate size and ignited in the muffle to a dull red, being maintained at this temperature a sufficient length of time to insure a complete oxidation of the organic matter. After cooling, 10 cc. of distilled water, 10 cc. of nitric acid and 5 cc. of hydrofluoric acid are added, the mixture well stirred, and the contents of the dish evaporated on the steam bath until approximately 5 cc. remain, when an additional 5 cc. of hydrofluoric acid are added, the mixture again well stirred, and the evaporation continued to complete dryness. Evaporation with small quantities of nitric acid is to be repeated two or three times. After the final evaporation the residue is dried in the air bath for 1 or 2 hours at 110°C. in order, as Washington (11, p. 163) states, "to render insoluble any silica which might otherwise come down with the phosphorus." When cool the residue is taken up with 3 cc. of concentrated nitric acid and 7 cc. of distilled water, boiled gently for a few minutes, and after cooling somewhat, is filtered and washed; the phosphorus in the filtrate is precipitated with ammonium molybdate,[3] and finally weighed as magnesium pyrophosphate. With soils poor in phosphorus a larger sample of soil should be taken and the amounts of the reagents proportionally increased.

The cause of the phosphoric acid remaining in the residue when this (after evaporation of the nitric acid) has been heated too strongly appears to be due to a reaction with iron and aluminum salts to form difficultly-soluble phosphates. Grandeau (5, p. 268) called attention to the fact that if the residue left after evaporation with nitric acid is heated to glowing, the oxides of iron and aluminum combine with small amounts of phosphoric acid and are only sparingly soluble in nitric acid. The author, using solutions containing known amounts of iron as ferrous ammonium sulfate, aluminum as aluminum sulfate and phosphoric acid as sodium phosphate, added hydrofluoric and nitric acids and continued the analysis according to Washington's method, including an ignition at dull redness previous to final treatment with nitric acid. This was done both with the solution alone in different amounts and with it added to soils A and B. As will be seen from table 10 the phosphoric acid was not completely recovered, but the deficit was fully accounted for by the amount obtained in the residue by fusion with sodium carbonate. The amount in the residue constituted in all cases a large part of the whole. There was no definite increase in this proportion due to the use of a larger amount of the solution of iron and aluminum.

Using the same soils and solutions, the determinations were made also by the author's modification of the Washington method, the results being given in the second part of the same table. All the phosphoric acid was recovered in the nitric acid extract, the residue retaining either no phosphoric acid or at most practically a negligible quantity.

Hilgard's method

The Hilgard method (6) for the determination of the acid-soluble phosphoric acid, which consists of the ignition of the soil and then digestion with concentrated nitric acid on the water bath for 2 days, gives as complete an

[3] An acid solution of ammonium molybdate was used throughout this study.

TABLE 10

Phosphoric acid as found after the addition of known amounts of iron, alum num, and phosphorus

SOIL	DETERMINATION	CONTENT OF SOLUTION ADDED, EXPRESSED AS PER CENT OF SOIL			PHOSPHORIC ACID			TOTAL AMOUNT RECOVERED
		Fe_2O_3	Al_2O_3	P_2O_5	In soil	In nitric acid	In residue	
		1. By Washington's method						
					per cent	*per cent*	*per cent*	*per cent*
	Solution 1	2.0	5.0	1.020		0.944	0.057	1.001
	2	2.0	5.0	1.020		0.914	0.096	1.010
	Average.....	2.0	5.0	1.020		0.929	0.077	1.006
	1	2.0	5.0	1.020		1.178	0.070	1.248
A....	2	2.0	5.0	1.020		1.167	0.108	1.275
	Average.....	2.0	5.0	1.020	0.245	1.173	0.089	1.262
	1	2.0	5.0	1.020		1.275	0.070	1.345
B....	2	2.0	5.0	1.020		1.282	0.057	1.339
	Average.....	2.0	5.0	1.020	0.334	1.278	0.064	1.342
	Solution 1	5.0	10.0	1.020		0.860	0.153	1.013
	1	5.0	10.0	1.020		1.170	0.089	1.259
A....	2	5.0	10.0	1.020		1.190	0.096	1.286
	Average.....	5.0	10.0	1.020	0.245	1.180	0.092	1.272
	1	5.0	10.0	1.020		1.230	0.134	1.364
B....	2	5.0	10.0	1.020		1.230	0.121	1.351
	Average.....	5.0	10.0	1.020	0.334	1.230	0.127	1.357
		2. By author's modification of Washington's method						
	Solution 1	2.0	5.0	1.020		1.020	0.000	1.020
	2	2.0	5.0	1.020		1.026	0.000	1.026
	Average.....	2.0	5.0	1.020		1.023	0.000	1.023
	1	2.0	5.0	1.020		1.262	0.006	1.268
A ...	2	2.0	5.0	1.020		1.243	0.019	1.262
	Average.....	2.0	5.0	1.020	0.245	1.252	0.013	1.265
	1	2.0	5.0	1.020		1.345	0.000	1.345
B....	2	2.0	5.0	1.020		1.332	0.012	1.344
	Average.....	2.0	5.0	1.020	0.334	1.339	0.006	1.345

The author has found in using an artificial soil solution containing ferrous ammonium sulfate equivalent to 5 per cent Fe_2O_3, aluminum sulfate equal to 10 per cent Al_2O_3 and sodium phosphate equal to 0.255 per cent P_2O_5 (expressed as per cent of soil) that it required the addition of an amount of

extraction as the Washington method when the latter is used without taking the precaution of avoiding over-heating the residue from the nitric acid extraction (table 4). The completeness of the extraction by this method is of especial interest on account of the great number of determinations carried out in the laboratory of its famous author and the valuable conclusions based upon these. Were there an actual danger of loss of phosphoric acid by volatilization through ignition before digestion much of his data would doubtless have been far too low. However, as it has been shown that there is no reason to suspect loss by volatilization we have no reason to question the reliability of his data. Practically as much phosphorus was extracted from sample A by this method as by the Fischer method, but contrary to what would be expected, considerably less from sample B.

TABLE 11

Phosphoric acid as found by Hilgard's method

SOIL	DETERMINATION	IN NITRIC ACID EXTRACT	IN RESIDUE	TOTAL AMOUNT
		per cent	*per cent*	*per cent*
A	1	0.210	0.025	0.235
	2	0.210	0.032	0.242
	Average	0.210	0.029	0.239
B	1	0.293	0.032	0.325
	2	0.286	0.038	0.324
	Average	0.290	0.035	0.325

A summary of the results obtained by the different methods is shown in table 12.

Influence of titanium

The presence of titanium has been regarded as tending to retard the precipitation of ammonium phosphomolybdate (8, p. 594). Little work on the subject has been reported and the most of that done has been in connection with the determination of phosphorus in steel or in iron ore, where the percentage is relatively high when compared with the amount usually found in soil.

titanium sulfate equivalent to 2.5 per cent or more of TiO_2 to interfere seriously with the recovery of the phosphorus (table 13). A higher percentage seriously affected the accuracy of the determination.

Robinson (9, p. 12–13) in a study on 26 soils from 13 different types finds the percentage of TiO_2 to vary between 0.40 and 1.59 per cent with an average of 0.86 per cent for all, while the author (1, p. 422), in examining 36 samples of loess soil, found the upper and lower limits of TiO_2 present to be 1.30 and 0.96 per cent, respectively, with a general average of 1.09 per cent.

TABLE 12

Phosphoric acid as found by the different methods

METHOD	SOIL	NUMBER OF DETERMINATIONS AVERAGED	IN NITRIC ACID EXTRACT	IN FILTRATE FROM YELLOW PRECIPITATE	IN RESIDUE	TOTAL AMOUNT RECOVERED
			per cent	*per cent*	*per cent*	*per cent*
Fusion unmodified	A	2	0.236	0.000	0.009	0.245
	B	2	0.322	0.000	0.012	0.334
Fusion sesquioxides precipitated	A	2	0.245	0.000	0.000	0.245
	B	2	0.328	0.000	0.009	0.337
Fusion $Mg(No_3)_2$ modification	A	2	0.233	0.000	0.009	0.242
	B	2	0.334	0.000	0.003	0.337
Fischer	A	6	0.211	0.000	0.030	0.241
	B	7	0.321	0.000	0.008	0.329
Washington	A	9	0.190	0.000	0.058	0.248
	B	6	0.303	0.000	0.031	0.336
Washington, Robinson's modification	A	2	0.147	0.051	0.054	0.252
	B	2	0.188	0.051	0.092	0.331
Washington, author's modification	A	2	0.245	0.000	0.000	0.245
	B	2	0.331	0.000	0.000	0.331
Hilgard	A	2	0.210		0.029	0.239
	B	2	0.290		0.035	0.325

From data reported in table 13 it is evident that the amount of titanium usually present in soil, or even the maximum amount found by Robinson, is too low to affect the determination of the phosphorus.

TABLE 13

Phosphoric acid as found in a standard solution after the addition of known amounts of titanium

SOLUTION	CONTENT OF SOLUTION ADDED EXPRESSED AS PER CENT OF SOIL				P_2O_5 RECOVERED		
	Fe_2O_3	Al_2O_3	TiO_2	P_2O_5	Set 1*	Set 2	Average
					per cent	*per cent*	*per cent*
1	5.0	10.0	1.0	0.255	0.255	0.248	0.251
2	5.0	10.0	1.5	0.255	0.255	0.255	0.255
3	5.0	10.0	2.5	0.255	0.236	0.242	0.239
4	5.0	10.0	5.0	0.255	0.147	0.197	0.172
5	5.0	10.0	10.0	0.255	0.019	0.032	0.025

* Sets 1 and 2 were run on different days.

SUMMARY

1. Six methods were compared, viz., fusion with sodium carbonate, the Fischer and Hilgard methods involving extraction with strong acid, Washington's hydrofluoric acid method, a modification of the last recently proposed by Robinson and a modification developed by the author.

2. With the fusion method usually only a negligible quantity of phosphoric acid was recoverable from the separated silica. Neither evaporation with magnesium nitrate previous to ignition nor precipitation of the phosphoric acid with the sesquioxides of iron and aluminum in order to separate it from the excess of sodium salts was found advantageous.

3. The Fischer method recovered practically all the phosphoric acid in the peat soils, but in most cases with mineral soils a considerable amount was left in the insoluble residue. None was lost by volatilization or rendered unrecoverable by the formation of compounds of iron and aluminum insoluble in nitric acid. That left in the residue was the result of an incomplete extraction by the acids employed.

4. The Hilgard method for the determination of acid-soluble phosphoric acid extracted as much from one soil as did the Fischer method, but in the case of another considerably less.

5. Washington's method, when applied to soils and modified to the extent of igniting the residue to dull redness after the final evaporation with nitric acid, failed to recover the whole of the phosphoric acid present. The residues upon being fused with sodium carbonate yielded the missing amount, thus showing that the low percentages found by this method are not due to volatilization during ignition but to incompleteness of extraction by nitric acid.

6. Robinson's modification of Washington's method extracted only from 50 to 65 per cent of the total phosphoric acid, the remainder being found partly in the residue and partly in the filtrate from the yellow precipitate. With soils high in organic matter the magnesium pyrophosphate obtained by this modification of the method carried a considerable amount of magnesium oxide, which was derived from precipitated organic compounds. A temperature so low that no glowing was produced failed to oxidize the organic matter completely. Samples analyzed by this modification of Washington's method with the exception that, after the first evaporation with nitric acid, they were ignited to very dull redness, behaved similarly, although no phosphoric acid was found in the filtrate from the yellow precipitate.

7. Two peat soils analyzed both with and without evaporation with magnesium nitrate solution previous to the ignition, gave no increased amount of phosphoric acid from treatment with this reagent, showing that there was no loss of phosphoric acid by volatilization during ignition. A sample of mineral soil mixed with 0.5 gm. of sugar and carefully ignited showed no loss of phosphorus by volatilization.

8. The incomplete extraction of the phosphorus from soils by Washington's method was found to be due to overheating the residue, causing the formation of difficultly-soluble phosphates of iron and aluminum.

9. The Washington method may be modified slightly so as to provide for the complete oxidation of the organic matter and the subsequent complete extraction of the phosphoric acid without making it less satisfactory for soils than it has proven for rocks. The prominent features of this proposed modification of the method consist of an ignition at dull redness previous to the treatment with hydrofluoric and nitric acids and later taking up the phosphoric acid with nitric acid, and drying the residue in an air bath at 110°C.

10. The amount of titanium oxide found in soils is too low to interfere with the precipitation of the phosphorus.

REFERENCES

(1) ALWAY, F. J., AND ROST, C. O. 1916 The loess soils of the Nebraska portion of the Transition Region: IV. Mechanical composition and inorganic constituents. *In* Soil Sci., v. 1, no. 5, p. 405–436, 2 fig.

(2) CAIN, J. R., AND HOSTETTER, J. C. 1912 A rapid method for the determination of vanadium in steels, ores, etc., based on its quantitative inclusion by the phosphomolybdate precipitate. *In* Jour. Indus. Engin. Chem., v. 4, no. 4, p. 250–256.

(3) FISCHER, HERMANN 1913 Die Bestimmung der Gesamptphosphorsäure im Boden. *In* Internat. Mitt. Bodenk., Bd. 2, p. 541–548.

(4) GORTNER, R. A., AND SHAW, WM. 1916 Does vanadium interfere with the determination of phosphorus in soils when the phosphorus is weighed as magnesium pyrophosphate? *In* Soil Sci., v. 2, no. 3, p. 299–304.

(5) GRANDEAU, L. 1897 Traité d' Analyse des Matières Agricoles. Ed. 3, 558 p., 171 fig. Paris.

(6) HILGARD, E. W. 1893 Methods of physical and chemical analysis. *In* Cal. Agr. Exp. Sta. Cir. 6, 23 p., 1 fig.

(7) HILLEBRAND, W. F. 1910 The analysis of silicate and carbonate rocks. U. S. Geol. Survey Bul. 422, 239 p.

(8) MELLOR, J. W. 1913 A treatise on Quantitative Inorganic Analysis, v. 1, 778 p. 206 fig. Philadelphia.

(9) ROBINSON, W. O. 1914 The inorganic composition of some important American soils. U. S. Dept. Agr. Bul. 122, 27 p.

(10) ROBINSON, W. O. 1916 A comparison of methods for the determination of soil phosphorus. *In* Jour. Indus. Engin. Chem., v. 8, no. 2, p. 148–151.

(11) WASHINGTON, H. S. 1910 Manual of Chemical Analysis of Rocks. Ed. 2, 200 p. New York.

HYDROGEN-ION CONCENTRATION MEASUREMENTS OF SOILS OF TWO TYPES: CARIBOU LOAM AND WASHBURN LOAM

LOUIS J. GILLESPIE AND LEWIS A. HURST

Soil Fertility Investigations, Bureau of Plant Industry, United States Department of Agriculture

Received for publication June 9, 1917

INTRODUCTION

In work recorded in an earlier paper (7) a number of soils of different type and origin were examined to determine the applicability of measurements of hydrogen-ion concentration to the soil. It was found possible to determine the hydrogen-ion concentration of soil extracts or soil suspensions in water by different methods: (1) an electrometric and (2) a simple colorimetric method. The results obtained by the two methods agreed sufficiently well to show that either method yields approximately correct results. The different soil samples exhibited widely different hydrogen-ion concentrations: the most acid soil showed the hydrogen-ion exponent[1] 4.4; the most alkaline, 8.6. More recently Sharp and Hoagland (12) have measured a variety of soils by the electrometric method and found exponents between the limits 3.7 and 9.7.

Wherry (16) has measured the hydrogen-ion concentration of some soils by the colorimetric method in a chemical study of the rocks and soils supporting the growth of the walking fern. Such soils showed exponents 5.5 to 9.0: the mean being 7.0.

Conner (5) estimated the intensity of acidity of soils by measuring the hydrolysis of ethyl acetate at the ordinary temperature. This method is not rapid, and the results which it yields have not yet been compared with those obtained by the above methods. Truog (13) has attempted to estimate the acidity by measuring the avidity of the "active" soil acids for bases: it is not clear just what relation this avidity would have to the hydrogen-ion concentration.

It will be recalled that the intensity of acidity is measured by the hydrogen-ion concentration, and that it bears in general no simple or direct relation

[1] Following the general custom, we report the "exponent" instead of the concentration itself. If desired, the concentration may be calculated by raising the number "10" to the power denoted by the exponent and finding the reciprocal of the result. Since, however, in practically all of the work on the biological significance of the hydrogen-ion concentration the results are stated in terms of the exponent, such a calculation is unnecessary. It need only be borne in mind that the exponent is about 7 for neutrality; and that the more alkaline, the greater is the value of the exponent; and the more acid, the lower the exponent.

to the quantity of acid present. It has been shown many times[2] that the hydrogen-ion concentration possesses a greater significance in biochemical processes than the quantity or concentration of acid substance. It is therefore entirely possible that certain problems of soil fertility, especially those relating to the necessity or desirability of liming for any specific crop, which have not as yet been solved by means of determinations of "lime requirement," may be solved by measurements of hydrogen-ion concentration.

The expression "to neutralize acidity" is ambiguous. It may mean to add alkali until there remains no excess of hydrogen ions over hydroxyl ions (physico-chemical standpoint); or it may mean to add alkali until acidic hydrogen atoms are all replaced (purely chemical or stoichiometrical standpoint), in which latter case the resulting reaction may be neutral, acid, or alkaline, depending on the nature of the salt formed. Most methods for estimating lime requirement, such as that of Veitch (14), are based on neutralization in the first sense; the method proposed by Bouyoucos (2) is based on neutralization in the second sense.

There is a current opinion that the rational liming of soils must be a process of neutralization, in one or the other of the above senses. This opinion seems not in accordance with the fact that many crops do well on soils regarded as acid; some, such as blueberries, have been found to require acid soils (6) others, such as potatoes, become liable to disease if liming is practiced. It would appear evident that what constitutes scientific corrective treatment of soil acidity, or soil alkalinity, cannot be settled by convention: we must find out what reaction (hydrogen-ion exponent) we ought to impart to the soil for any system of cropping, before we attempt to formulate rules for the adjustment.

SELECTION OF SOILS FOR EXAMINATION

In the earlier paper, cited above, no attempt was made to correlate the results found for the soils with the nature of the soils or with their biological characteristics, the soils under examination being too diverse. The measurements reported in this paper, on the other hand, have been made on soil samples grouped, according to the Bureau of Soils, into two types: Caribou loam and Washburn loam (15). The samples were taken from fields representative of large areas and conformed to one or the other of the two types.

Of the several kinds of soil upon which Irish potatoes are grown in northern Maine, the greater part of the crop is harvested from the Caribou loam and to a less extent from the Washburn loam. The types are quite similar in texture and are derived from the same parent materials, or glacial till; but, owing to certain topographic differences which affect particularly the local drainage, striking differences are found between soils of these types.

[2] See especially the monograph of Michaelis (11) and a recent paper by Clark and Lubs (4) for instances and literature.

The Caribou loam is characterized by the yellowish-brown color of the surface soil and even brighter subsurface soil (indicative of good drainage); whereas the surface of the Washburn loam is dark gray to black in color, and is underlaid by a light gray to a dull yellow and gray mottled subsurface soil, the latter being very characteristic of poorly-drained soils. The average depth of the surface soil of both types is about eight inches, which is probably one or two inches below the average plow depth. The Caribou loam occurs on high, well-drained ridges and slopes; the Washburn occurs in low-lying, flat or depressed situations, in which seepage or poor drainage naturally prevails. Such low situations favor the accumulation of muck and peat with which the Washburn loam is always covered until the land is cleared for cultivation. Similar mucky conditions do not occur on the virgin Caribou soils. The native vegetation of the Caribou loam is a hardwood growth of maple, yellow birch, white pine, balsam fir, and the like. The native timber growth of the Washburn loam is chiefly white cedar, except where the original timber has been destroyed by fire, when it is often replaced by other soft woods, such as poplar, white birch and cottonwood.

At least two-thirds of the potatoes grown in northern Maine are produced on the Caribou loam, which is in general better suited to potato culture than the Washburn loam. In connection with certain potato-disease studies carried on coöperatively by the Maine Agricultural Experiment Station and the United States Department of Agriculture, Schreiner, Lapham, and Westover in 1915 found that potato scab, particularly that caused by *Spongospora subterranea*, where it occurs at all, is largely on the Washburn loam, the Caribou loam being comparatively free from disease; and this has been confirmed by Hurst in 1916. An instance of the comparative freedom of the Caribou loam from infection of *Spongospora subterranea* has already been reported by Melhus, Rosenbaum, and Schultz (10). Soil 2.0 (p. 237–239) is the Caribou loam while 1.0 is the Washburn, the other numbers (1.1, 1.2, 2.1) being intermediate phases of the two types.

EXPERIMENTAL PROCEDURE

The procedure for the colorimetric determinations is much the same as that used before. We have found that acid soils may show a somewhat higher acidity when the soil extracts are made with 1 cc. of water per gram of air-dry soil than with 2 cc., the quantity used previously. Good duplication is obtainable with this ratio of 1 to 1. The average difference obtained by varying the ratio from 1 to 1, to 2 to 2 was 0.14 in the value of the exponent for nine soils. This indicates that at optimum moisture content the acidity may be more intense, but to what extent cannot be calculated. Only results between the same ratios of water to soil should be compared. We have used in the present work 1 cc. of water per gram of air-dry soil.

Most of the soil extracts (suspensions from which the heavier particles have been thrown out by means of a centrifuge) show an increased hydrogen-ion concentration when examined colorimetrically, if carbon dioxide is passed into them. If air which has been freed from carbon dioxide is blown through the extracts, some show very little change, others a moderate decrease of acidity, but all we have tried maintain their acidity to methyl red far longer than water, or suspension of bicarbonates, made acid to methyl red with carbon dioxide.[3]

When soils are dried in air, carbon dioxide is lost, for the pressure of carbon dioxide in the soil air is considerably higher than in the atmosphere. It has seemed more expedient for the present, however, to study air-dried soils. The procedure has therefore its theoretical limitations, and the acidities found may be somewhat low for the two reasons given above.

About thirty grams of air-dry soil, which had been passed through a 1-mm. sieve without grinding, were treated in a centrifuge tube of 100 cc. capacity with an equal number of cubic centimeters of distilled water. The tube was closed by the hand, and after thorough wetting of the soil was accomplished, the tube was violently shaken about fifty times. Not more than eight soils were thus treated at a time and the entire determination was carried out without delay. The tubes were centrifuged for ten to twenty minutes. The supernatant fluid was drawn off with a pipette provided with a rubber tube and a mouth-piece and distributed into test-tubes. To a small portion a drop of methyl red was added; the result showed whether methyl red could be used for the measurement, if not, other indicators were tried. To a 5-cc. portion of the fluid the proper indicator solution was added and admixed, and the color so developed was compared with the colors obtained on adding the same quantity of the same indicator solution to tubes containing 5 cc. of various "buffer solutions" of known hydrogen-ion exponents.

Most of the fluids were somewhat turbid, and the simple comparator of Hurwitz, Meyer and Ostenberg (8), as modified by Clark and Lubs (4), was used for the comparison.

The buffer mixtures were made from fifth-molecular solutions of acid potassium phthalate, acid potassium phosphate, and sodium hydrate, according to the proportions given by Clark and Lubs (3, 4). The hydrogen-ion exponents

[3] It should not hastily be assumed that hydrogen-ion concentrations due to carbon dioxide are of less physiological significance than those due to other acids. The hydrogen-ion concentration of the blood, which is so important a quantity that a special mechanism involving the regulation of lung activity has been elaborated for keeping it constant, is maintained constant by suitably adjusted changes in the carbon dioxide content in spite of variations resulting from the accession of various acid or alkaline substances. (See the monograph of Michaelis for discussion and references.)

When carbon dioxide is accompanied by carbonates in analytically significant quantities the hydrogen-ion concentration is far lower for moderate pressures than those reported here for the more acid class of soils. [A general discussion of the carbonate equilibrium has been given by Johnston (9).]

of the buffer mixtures were checked electrometrically. If the substances used are known to be pure this is unnecessary.

The following two indicators were used; methyl red, and bromcresol purple (dibrom-o-cresol-sulfone-phthalein). Both were used in water solution: methyl red, two drops of a 0.02 per cent solution of the sodium salt; and bromcresol purple, three drops of a 0.04 per cent solution of the sodium salt. Although a slight excess of alkali is necessary in order to dissolve the indicators (4), if the excess is very slight over the theoretical quantity (one equivalent) the resulting solutions appear to have, if anything, less buffer action than the alcoholic solutions formerly used. At any rate the two solutions used by us gave concordant values (about 5.8) of the hydrogen-ion exponent for the distilled water used.

In one or two cases it was observed that even with the comparator the color of the soil extract treated with brom-cresol purple could not be matched in value exactly with any of the buffer solutions containing this indicator. This is due to dichromatism. Clark and Lubs have pointed out the disturbing effect of dichromatism in turbid solutions of this indicator and have shown how to reduce it (4). We have viewed the solutions through thin layers (12 mm.) in the comparator, but have not used the screened source of light devised by them. For the present differentiation the error due to dichromatism was unimportant: in fact, the mere differentiation could have been effected, as it proved, by the use of methyl red alone.

EXPERIMENTAL RESULTS

The results for cultivated fields of soils of the Caribou loam type are given in table 1, and the corresponding results for the Washburn soils in table 2. The samples were taken from the first 8 inches. The soils are arranged in order of decreasing acidity. The indicator used for the Caribou soils was methyl red, for the Washburn soils the indicator was also methyl red except for the last five cases.

TABLE 1

Hydrogen-ion exponents of cultivated soils belonging to the Caribou loam type

Soil number	1	2	3	4	5	6	7	8	9	10	11	12	13
Exponent	4.85	5.0	5.05	5.1	5.15	5.2	5.2	5.25	5.3	5.3	5.3	5.35	5.45

TABLE 2

Hydrogen-ion exponents of cultivated soils of the Washburn loam type

Soil number	14	15	16	17	18	19	20	21	22	23	24
Exponent	5.4	5.5	5.7	5.7	5.8	5.8	5.8	6.25	6.3	6.4	6.65

A further interesting comparison is noted when these results are tabulated according to the occurrence of both types on the same field. This is done in table 3.

TABLE 3

Hydrogen-ion exponents of soils of the Caribou loam and Washburn loam, collected in the same field

FIELD	CARIBOU LOAM	WASHBURN LOAM	DIFFERENCE
A	5.00	5.80	0.80
B	5.15	5.50	0.35
C	5.30	5.70	0.40
D	5.35	5.70	0.35
E	5.10	6.40	1.30
F	5.20	5.40	0.20
G	5.25	5.80	0.55
H	5.20	6.30	1.10
I	5.45	6.65	1.20

When one considers that the two types in each of these fields received exactly the same treatment in fertilization and cultivation, it shows that the differences are not accidental but are characteristic of the soil type. It should further be emphasized that these Maine potato soils have never been limed.

DISCUSSION OF THE RESULTS

The mean value of the exponent for the Caribou soils is 5.2; that for the Washburn soils, 5.93. Although all of the soils examined are acid, the Caribou soils are as a class, indeed almost without exception, more intensely acid than the Washburn soils. Of the general biological differences of the two types, the more interesting are those relating to the occurrence of potato scabs, since the growth of the causal organisms might be inhibited by the acidity of the Caribou soils but not by that of the Washburn soils. It has been shown for a number of microorganisms that growth is impossible beyond a certain intensity of acidity, as measured by the hydrogen-ion exponent. As compiled from various authorities by Clark and Lubs (4) the acid limit for six species studied lies above the acidity represented by the exponent 5.3. For a certain group of *Streptococci*, however, described by Ayers (1), the limiting exponents lie between 5.5 and 6.0, and without doubt other microorganisms will be found to fail to grow at such hydrogen-ion concentrations.

It is therefore not impossible that the relative freedom of soils of the Caribou type from disease may be due to the greater intensity of acidity.

SUMMARY

The Caribou loam and the Washburn loam from Aroostook County, Maine, possess before cultivation broadly different biological characteristics. Both types are largely devoted to potato culture, the Caribou loam being better adapted to this than the Washburn loam.

Cultivated soils of the Caribou loam type exhibit, when examined by the colorimetric method, considerably greater hydrogen-ion concentrations than do soils of the Washburn loam type. The average hydrogen-ion exponent for the Caribou loam was found to be 5.2; that of the Washburn loam 5.93.

The possibility is indicated that the relative freedom of the Caribou loam from potato scabs may be due to its greater hydrogen-ion concentration.

LITERATURE CITED

(1) AYERS, S. HENRY. 1916 Hydrogen-ion concentrations in cultures of Streptococci. *In* Jour. Bact., vol. 1, no. 1, p. 84–85.

(2) BOUYOUCOS, GEORGE, J. 1916 The freezing-point method as a new means of determining the nature of acidity and lime requirements of soils. Mich. Agr. Exp. Sta. Tech. Bul. 27, 52 p., 18 fig.

(3) CLARK, WILLIAM MANSFIELD, AND LUBS, HERBERT A. 1916 Hydrogen electrode potentials of phthalate, phosphate, and borate buffer mixtures. *In* Jour. Biol. Chem., vol. 25, no. 3, p. 479–510, 2 fig.

(4) CLARK, WILLIAM MANSFIELD, AND LUBS, HERBERT A. 1917 The colorimetric determination of hydrogen-ion concentration and its applications in bacteriology. *In* Jour. Bact., vol. 2, no. 1, p. 1–34, no. 2, p. 109–136, no. 3, p. 191–236, 9 fig.

(5) CONNER, S. D. 1916 Acid soils and the effect of acid phosphate and other fertilizers upon them. *In* Jour. Indus. Engin. Chem., vol. 8, no. 1, p. 35–40, 2 fig.

(6) COVILLE, FREDERICK V. 1915 Directions for blueberry culture, 1916. U. S. Dept. Agr. Bul. 334, 16 p., 17 pl.

(7) GILLESPIE, L. J. 1916 The reaction of soil and measurements of hydrogen-ion concentration. *In* Jour. Wash. Acad. Sci., vol. 6, no. 1, p. 7–16, 2 fig.

(8) HURWITZ, S. H., MEYER, K. F., AND OSTENBERG, Z. 1916 A colorimetric method for the determination of the hydrogen-ion concentration of biological fluids, with special reference to the adjustment of bacteriological culture media. *In* Bul. Johns Hopkins Hospital, vol. 27, (no. 299), p. 16–24, 2 fig., 2 charts.

(9) JOHNSTON, JOHN 1916 The determination of carbonic acid, combined and free, in solution, particularly in natural waters. *In* Jour. Amer. Chem. Soc., vol. 38, no. 5, p. 947–975.

(10) MELHUS, I. E., ROSENBAUM, J., AND SCHULTZ, E. S. 1916 Spongospora subterranea and Phoma tuberosa on the Irish potato. *In* Jour. Agr. Research., vol. 7, no. 5, p. 213–254, 1 fig., 14 pl.

(11) MICHAELIS, LEONOR 1914 Die Wasserstoffionenkonzentration. 210 p., 41 fig., Berlin. Literaturverzeichnis, p. 196–207.

(12) SHARF, L. T., AND HOAGLAND, D. R. 1916 Acidity and adsorption in soils as measured by the hydrogen electrode. *In* Jour. Agr. Research., vol. 7, no. 3, p. 123–145, 1 fig.

(13) TRUOG, E. 1916 A new apparatus for the determination of soil carbonates and new methods for the determination of soil acidity. *In* Jour. Indus. Engin. Chem., vol. 8, no. 4, p. 341–345, 2 fig.

(14) VEITCH, F. P. 1902 The estimation of soil acidity and the lime requirements of soils. *In* Jour. Amer. Chem. Soc., vol. 24, no. 11, p. 1120–1128.

(15) WESTOVER, H. L., AND ROWE, R. W. 1910. Soil survey of the Caribou area, Maine. 40 p., 1 fig., 1 map, Washington.

(16) WHERRY, EDGAR T. 1916 A chemical study of the habitat of the walking fern, Camptosorus rhizophyllus (L.) Link. *In* Jour. Wash. Acad. Sci., vol. 6, no. 20, p. 672–679.

FURTHER STUDIES OF THE NATURE OF AMMONIFICATION

K. MIYAKE

College of Agriculture, Tohoku Imperial University, Sapporo, Japan[1]

Received for publication July 11, 1917

It has been proved by the author (1) that the process of ammonification and nitrification are autocatalytic chemical reactions and that the increase of ammonia and nitric acid in these processes are in accordance with the formula

$$\log \frac{x}{A-x} = K(t-t_1)$$

where x is the amount of nitrogen in the form of ammonia and of nitric acid which has been produced at the time t, A is the total amount of nitrogen in the form of ammonia and of nitric acid produced during the process, K is a constant, and t_1 is the time in which half of the total amount of nitrogen in the form of ammonia and of nitric acid is produced. This proof has been secured by the application of the autocatalytic chemical equation to the results of Lipman's, Lemmermann's and Warington's experiments. It will be both interesting and important, therefore, to test the proof of this subject further by personal experiments.

The present paper deals with the results of ammonification. The results of nitrification will be treated elsewhere later.

EXPERIMENTAL

Five different soils—Caribou silt loam, and Washburn silt loam from Maine, Superior clay from Wisconsin, Scottsburg silt loam from Indiana, and soil from the Arlington farm, Virginia, were selected and used for the experiment in an air-dried condition after having been passed through a 1-mm. sieve. Leucine and tyrosine were used as the chemicals to be ammonified. These were made in the laboratory by us from casein and from horn meal.

For the experiment 100 gm. of the soils and the chemicals equivalent to 100 mgm. of nitrogen were used. The amount of leucine and tyrosine used is, therefore, 0.9372 and 1.2943 gm., respectively. To the mixture 10 cc. of water was added and well mixed. The treated soils were kept in bottles. After incubation at a constant temperature (30°C.) for certain intervals of time as indicated in the following table, 10 gm. of the soils were taken and ammonia was determined by the usual distillation method with magnesia. In

[1] The investigations recorded in this paper were carried out in the laboratory of Soil Fertility Investigations, Bureau of Plant Industry, United States Department of Agriculture.

all cases the amount of ammonia obtained by distillation of the soil without addition of any compound, was subtracted from the quantity of ammonia found on distillation of the treated soils after they had undergone the process of ammonification. By weighing the bottles every morning we confirmed that the water content of the soils remained almost constant throughout the experiment.

The result obtained is as follows:

TABLE 1

Milligrams of ammonia nitrogen actually produced from the compounds equivalent to 100 mgm. of nitrogen in 100 gm. of the soils and calculated by the equation given

1. Result with Arlington soil

a. Equation for leucine:

$$\log \frac{x}{78.46 - x} = 0.2032\ (t - 6.85)$$

b. Equation for tyrosine:

$$\log \frac{x}{64.00 - x} = 0.1634\ (t - 8.15)$$

DAYS	LEUCINE		TYROSINE	
	Calculated	Found	Calculated	Found.
	mgm.	*mgm.*	*mgm.*	*mgm.*
2	7.35	7.77	5.76	3.12
5*	23.24	23.30	14.98	15.58
7	40.60	46.59	25.19	24.93
9*	57.43	62.12	37.07	37.39
12*	71.99	71.44	51.84	50.08
14	75.79	74.55	58.24	56.09
16*	77.38	77.66	61.17	61.21

2. Result with caribou soil

a. Equation for leucine:

$$\log \frac{x}{78.08 - x} = 0.1602\ (t - 8.3)$$

b. Equation for tyrosine:

$$\log \frac{x}{71.62 - x} = 0.1816\ (t - 8.3)$$

DAYS	LEUCINE		TYROSINE	
	Calculated	Found	Calculated	Found
	mgm.	*mgm.*	*mgm.*	*mgm.*
2	6.96	7.77	4.79	3.12
5*	17.83	17.20	14.39	12.80
7	29.85	29.95	26.31	26.71
9*	44.03	44.93	41.01	41.17
12*	62.19	59.02	59.04	57.87
14	69.55	67.12	65.58	65.11
16*	73.78	73.22	68.87	69.00

TABLE 1—*Continued*

3. Result with Indiana soil

a. Equation for leucine:

$$\log \frac{x}{84.53 - x} = 0.0992\ (t - 8.55)$$

b. Equation for tyrosine:

$$\log \frac{x}{42.98 - x} = 0.1222\ (t - 8.87)$$

DAYS	LEUCINE		TYROSINE	
	Calculated	Found	Calculated	Found
	mgm.	*mgm.*	*mgm.*	*mgm.*
2	15.47	8.32	5.43	3.34
5*	26.01	24.41	10.83	10.02
7	34.86	34.17	15.96	15.58
9*	44.44	44.37	21.88	21.81
12*	58.11	57.13	30.38	30.61
14	65.65	65.23	34.77	34.28
16*	71.49	71.44	37.89	38.40

4. Result with Superior soil

a. Equation for leucine:

$$\log \frac{x}{82.76 - x} = 0.1275\ (t - 7.17)$$

b. Equation for tyrosine:

$$\log \frac{x}{58.36 - x} = 0.2045\ (t - 5.35)$$

DAYS	LEUCINE		TYROSINE	
	Calculated	Found	Calculated	Found
	mgm.	*mgm.*	*mgm.*	*mgm.*
2	14.88	15.53	9.99	7.23
5*	28.63	24.85	27.87	26.15
7	40.34	40.38	39.77	40.51
9*	52.27	52.81	49.46	48.30
12*	66.62	65.23	55.92	54.53
14	72.93	74.55	57.39	56.20
16*	77.02	77.66	58.14	57.65

5. Result with Washburn soil

a. Equation for leucine:

$$\log \frac{x}{82.74 - x} = 0.201\ (t - 4.3)$$

b. Equation for tyrosine:

$$\log \frac{x}{79.56 - x} = 0.0916\ (t - 5.75)$$

DAYS	LEUCINE		TYROSINE	
	Calculated	Found	Calculated	Found
	mgm.	*mgm.*	*mgm.*	*mgm.*
2	21.14	10.87	24.82	12.46
5*	48.03	48.15	36.64	35.84
7	64.31	69.89	44.96	45.19
9*	74.31	76.20	52.90	51.42
12*	80.44	79.20	62.76	61.21
14	81.82	80.76	67.68	66.22
16*	82.37	82.32	71.34	70.12

* These points were used for the calculation of value A.

It will be seen from the table that the observed and calculated values of x are in good agreement. There is, therefore, no doubt that the process of ammonification is an autocatalytic chemical reaction and that the increase of ammonia in this process is in accordance with the formula $\log \frac{x}{A-x} = K(t-t_1)$, as stated in the previous paper.

From the practical standpoint, it might be considered that while the ammonification of a compound is still going on in the soil, a part of the ammonia produced is oxidized to nitrites and nitrates. The loss of nitrogen in the form of ammonia is also caused through denitrification. For such reasons, the ratio between the nitrogen in the compound added and the nitrogen in the ammonia produced never attains its final value. The total amount of nitrogen in the compound added, consequently, might be gradually transformed into nitrogen of ammonia form. But when we consider ammonification itself from the scientific standpoint, it is very interesting and important to know whether the total amount of nitrogen added will be ammonified. The rate of transformation of nitrogen in the process of ammonification will be clearly shown by the equation, because A in the equation denotes the maximum amount of nitrogen produced in the form of ammonia. The actual value of A is, however, always less than the amount of nitrogen added. This means that the nitrogen added is not totally transformed into the nitrogen in the form of ammonia in the process of ammonification. For the sake of convenience we have brought together our results in table 2.

TABLE 2

Rate of transformation of nitrogen in the process of ammonification

SOILS	LEUCINE		TYROSINE	
	Nitrogen added	Value of A	Nitrogen added	Value of A
	mgm.	*mgm.*	*mgm.*	*mgm.*
Arlington	100.00	78.46	100.00	64.00
Caribou	100.00	78.08	100.00	71.62
Indiana	100.00	84.53	100.00	42.98
Superior	100.00	82.76	100.00	58.36
Washburn	100.00	82.74	100.00	79.56

The rate of transformation seems to be dependent upon the conditions of the experiment as to soils, chemicals, moisture, temperature, etc. In our experiment, the value A for leucine was always greater than that for tyrosine, that is, leucine ammonified to a greater extent than did tyrosine. The value A of each compound was also greatly influenced by the soils.

SUMMARY

1. We have confirmed again that the process of ammonification is an autocatalytic chemical reaction and that the increase of ammonia in the process is in accordance with the formula:

$$\log \frac{x}{A-x} = K\,(t - t_1).$$

2. The total amount of nitrogen added to be ammonified does not transform into the nitrogen in the form of ammonia in the process of ammonification.

3. The amount of nitrogen transformed into ammonia nitrogen is greatly influenced by both the soils and chemical compounds used.

In conclusion, it is a pleasure for the author to acknowledge his indebtedness to Dr. Oswald Schreiner and Dr. Elbert C. Lathrop, of the Bureau of Plant Industry, United States Department of Agriculture.

REFERENCES

(1) MIYAKE, K. 1916 On the nature of ammonification and nitrification. *In* Soil Sci., v. 2, p. 481–492.

NITRIFICATION AS A MEASURE OF THE AVAILABILITY OF DIFFERENT FORMS OF CALCIUM CARBONATE WHEN EMPLOYED AS CORRECTORS OF SOIL ACIDITY

P. S. BURGESS

Hawaiian Sugar Planters' Experiment Station, Honolulu, T. H.

Received for publication March 5, 1917

Last July a sample of finely-ground, soft coral limestone was submitted to this laboratory for analysis by one of the local lime companies. A request for our opinion of the material as a corrector of soil acidity accompanied the sample. The analysis of this limestone appears in table 1.

TABLE 1

Analysis of soft coral limestone

	per cent
Moisture	1.2
Volatile matter (chiefly CO_2)	41.2
SiO_2, Al_2O_3, Fe_2O_3	2.4
Lime (CaO)	52.6
Magnesia (MgO)	1.3
Phosphorus pentoxide (P_2O_5)	0.1
Sulfur trioxide (SO_3)	0.6
Lime calculated as carbonate	93.6

After receiving the above report the company in question desired us to make a few tests, if possible to ascertain the solubility or availability of this finely-ground product as compared with coral sand which at present is being quite generally applied to soils in the acid districts. Thinking this to be a subject of some importance to the plantations located on the acid soils of Hawaii, as well as a subject of some scientific interest, a series of experiments were planned to test out the relative rates of availability of the two forms of lime carbonate in question. The results of these experiments form an excuse for the publication of this article.

There are two points to be recognized and remembered in reading this report. First, coral sand and finely ground coral limestone are identical chemically—their only difference lies in mechanical condition, i.e., degree of fineness and hardness of grain. Second, in applying lime to sugar cane lands for the correction of soil acidity we do it, not so much to benefit the cane plant directly (for we know that, if properly fertilized, cane can be grown on very acid soils), as to enhance beneficial bacterial activity. If this is accomplished, available plant-food is at all times being prepared, resulting in a more normal feeding of the cane, and eventually in increased yields.

At first this problem of lime availability appeared somewhat puzzling, for time did not permit of extended vegetative tests with growing plants. Furthermore, it is obviously impossible to add the materials to exact neutrality in an acid soil and determine the rates of availability by the ordinary lime requirement methods, for, if correct amounts of the materials were added upon such chemical analysis a neutral soil would at all times result, irrespective of the size of the calcium carbonate particles. In fact, the Veitch method *was* tried which showed the futility of such a method of attack. It then occurred to the writer that, while nitrification is low in an acid soil, it picks up with remarkable celerity upon the addition of lime carbonate *in readily available forms*. On the other hand, if lime carbonate is added in chunks or in unavailable forms, as in hard shells or coarse marble fragments, nitrification would be enhanced but slightly.

The plan of the investigation follows.

About 100 pounds of a very acid surface soil was secured, through the courtesy of Mr. W. P. Naquin, from one of the upper fields of the Pacific Sugar Mill at Kukuihaele, Hawaii. It is a reddish brown clay loam of considerable potential fertility and previous experiments had shown it to contain a nitrifying flora which awaited only a proper lime application to render it vigorously active. An analysis of this soil is given in table 2.

TABLE 2

Analysis of Kukuihaele Mauka surface soil

Agricultural method of analysis (1)

	per cent
Phosphoric acid (P_2O_5)	0.88
Potash (K_2O)	0.33
Lime (CaO)	0.31
Total nitrogen	0.44

Citrate-soluble analysis [Dyer's modified method] (1)

Phosphoric acid (P_2O_5)	0.0018
Potash (K_2O)	0.0283
Lime (CaO)	0.0560

Lime-requirement (Veitch method) 1.068 per cent lime carbonate (16 tons per acre-foot).

This soil, as it exists in the field, is of good physical condition but underlain at a depth of about 6 inches by a heavy, hard subsoil of somewhat lighter color.

The bag of soil, upon its arrival at the laboratory, was air-dried in the shade, sifted through a 3-mm. sieve and thoroughly mixed. Two hundred and sixteen 100-gm. portions were now weighed out into clean, sterile glass tumblers and covered with glass Petri dishes. These were arranged in 9 series of 12 duplicate soil cultures each. The treatment of each series was identical, being as follows:

NO.	TREATMENT
1– 1A	Blank on soil, exactly neutralized with coral sand
2– 2A	Blank on soil, exactly neutralized with ground limestone
3– 3A	0.3 gm. dried blood added (40.5 mgm. N)
4– 4A	0.3 gm. dried blood neutralized with coral sand
5– 5A	0.3 gm. dried blood twice neutralized with coral sand
6– 6A	0.2 gm. ammonium sulfate added (42.4 mgm. N)
7– 7A	0.2 gm. ammonium neutralized with coral sand
8– 8A	0.2 gm. ammonium twice neutralized with coral sand
9– 9A	0.3 gm. dried blood added, neutralized with ground limestone
10–10A	0.3 gm. dried blood added, twice neutralized with ground limestone
11–11A	0.2 gm. ammonium sulfate added, neutralized with ground limestone
12–12A	0.2 gm. ammonium sulfate added, twice neutralized with ground limestone

A brief explanation of these treatments may not be superflous. The coral sand employed was of very good quality. Only that portion between 0.5 mm. and 1mm. in size was used. This treatment eliminated all of the larger grains of sand, shells, sticks, pieces of seaweed, etc. Upon analysis it was found to contain 89 per cent of lime carbonate. An analysis of the finely-ground coral limestone appears in table 1. In supplying both of these materials to the cultures, allowances were made for contained impurities so that equal and correct percentages of *lime carbonate* ($CaCO_3$) were added in all cases to neutralize the soil acidity exactly, or double this amount, as the case might be.

In soil cultures 1 and 1A no nitrogen was added. Enough coral sand was supplied to neutralize the soil acidity exactly.

Soil cultures 2 and 2A were treated in exactly the same way as no. 1 and 1A, except that ground limestone was here substituted for the coral sand.

Soil cultures 3 and 3A received 0.3 gm., of dried blood only (40.5 mgm. organic nitrogen).

Soil cultures 4 and 4A were exactly the same as no. 3 and 3A, except that the soil acidity was here exactly neutralized with coral sand.

Soil cultures 5 and 5A were the same as no. 3 and 3A, with the exception that here twice as much coral sand as required was added.

Soil cultures 6 and 6A received 0.2 gm. of ammonium sulfate only (42.4 mgm. ammonia nitrogen).

Soil cultures 7 and 7A were the same as no. 6 and 6A, except that here enough coral sand to neutralize soil acidity exactly was added.

Soil cultures 8 and 8A were identical with no. 6 and 6A, except that twice as much coral sand was added as was actually needed.

Soil cultures 9 and 9A received 0.3 gm. of dried blood and exactly enough ground coral limestone to neutralize the soil acidity.

Soil cultures 10 and 10A were similar to no. 9 and 9A, except that here twice as much ground limestone was added.

Soil cultures 11 and 11A received 0.2 gm. of ammonium sulfate each after being exactly neutralized with ground limestone.

Soil cultures 12 and 12A were the same as no. 11 and 11A except that twice as much ground limestone was added.

To all of the soil cultures optimum amounts of sterile distilled water were added. The incubation temperature was 28°C. Two cubic centimeters of water were added each week to each culture to make up for loss from evapora-

TABLE

Availability of coral sand and ground

SOIL CULTURE NO.	TREATMENTS	PERIOD OF INCU							
		2 weeks Series I		4 weeks Series II		6 weeks Series III		8 weeks Series IV	
		N nitrified per culture	Nitrogen nitrified	N nitrified per culture	Nitrogen nitrified	N nitrified per culture	Nitrogen nitrified	N nitrified per culture	Nitrogen nitrified
		mgm.	*per cent*	*mgm.*	*per cent*	*mgm.*	*per cent*	*mgm.*	*per cent*
1	Blank + sand.	4.00	0 .91	4.00	0.91	4.50	1.02	9.00	2.04
2	Blank + ground limestone.	4.80	1.09	4.50	1.02	6.00	1.36	9.00	2.04
3	Dried blood only.	4.80	11.8	4.20	10.4	7.50	18.5	12.00	29.6
4	Dried blood + sand.	9.00	22.2	10.00	24.7	12.00	29.6	18.00	44.4
5	Dried blood + 2 sand.	10.40	25.7	11.00	27.2	16.00	39.5	21.00	51.9
6	Ammonium sulfate only.	3.40	8.0	4.80	11.3	8.00	18.9	7.50	17.7
7	Ammonium sulfate + sand.	10.00	23.6	28.00	66.0	27.00	63.7	29.50	69.6
8	Ammonium sulfate + 2 sand.	15.00	35.4	30.00	70.7	28.00	66.0	33.00	77.8
9	Dried blood + ground limestone.	12.00	29.6	25.00	61.7	25.00	61.7	25.00	61.7
10	Dried blood + 2 ground limestone.	13.00	32.1	25.00	61.7	26.00	64.2	25.00	61.7
11	Ammonium sulfate + ground limestone	13.00	30.7	44.50	105.0	45.00	106.1	43.00	101.4
12	Ammonium sulfate + 2 ground limestone	32.00	75.5	45.00	106.1	45.00	106.1	44.00	103.8
Blank	Blank on soil, no additions. Incubated 20 weeks								

[1] These are averages of closely agreeing duplicate determinations.

tion. All nine series (216 cultures) were started together on August 7, 1916.

As the chief object of the experiment was to note the progressive effect of the different forms of lime carbonate on the nitrification of organic nitrogen and sulfate nitrogen, one series was dried out and analyzed for nitrates at the end of each period of 2 weeks during the first 16 weeks. The last, series IX, was allowed to incubate 5 months (20 weeks).

Table 3 imparts all of the data obtained, while figure 1 graphically presents these same results. It should be stated that nitrates were determined in these cultures by the modified phenoldisulphonic acid method of Gill (2), calcium carbonate (3) being used as the flocculating agent.

Before discussing the data here presented it should be stated that, under mainland conditions according to data previously secured by the writer and by others, the amounts of nitrate nitrogen biologically formed during one

3

coral limestone as measured by nitrification[1]

BATION OF CULTURES										GENERAL AVERAGES OF ALL SERIES	
10 weeks Series V		12 weeks Series VI		14 weeks Series VII		16 weeks Series VIII		20 weeks Series IX			
N nitrified per culture	Nitrogen nitrified	N nitrified per culture	Nitrogen nitrified	N nitrified per culture	Nitrogen nitrified	N nitrified per culture	Nitrogen nitrified	N nitrified per culture	Nitrogen nitrified	N nitrified per cuiture	Nitrogen nitrified
mgm.	*per cent*	*mgm.*	*per cent*	*mgm.*	*per cent*	*mgm.*	*per cent*	*mgm.*	*per cent*	*mgm.*	*per cent*
12.00	2.73	9.00	2.04	10.00	2.27	8.00	1.82	9.00	2.04	7.72	1.75
12.00	2.73	10.00	2.27	11.00	2.50	7.50	1.70	9.00	2.04	8.20	1.86
18.00	44.4	16.00	39.5	13.00	32.1	9.00	22.2	11.00	27.2	10.50	25.9
20.00	49.4	22.00	54.3	25.00	61.7	20.00	49.4	20.00	49.4	17.33	42.8
24.00	59.3	27.00	66.7	25.00	61.7	22.00	54.3	28.00	69.1	20.50	50.6
8.00	18.9	7.00	16.5	6.00	14.1	6.00	14.1	7.50	17.7	6.46	15.2
30.00	70.7	30.00	70.7	31.00	73.1	24.00	56.6	22.00	51.9	25.65	60.5
32.00	75.5	32.00	75.5	32.00	75.5	25.00	59.0	30.00	70.7	28.55	67.3
26.00	64.2	26.00	64.2	26.00	64.2	25.00	61.7	28.00	69.1	24.62	60.8
30.00	74.1	29.00	71.6	28.00	69.1	lost		29.00	71.6	25.62	63.3
44.00	103.8	44.00	103.8	40.00	94.3	40.00	94.3	39.00	92.0	39.16	92.4
45.00	106.1	44.00	103.8	43.00	101.4	41.00	96.7	40.00	94.3	42.11	99.3
								1.60	0.36	1.60	0.36

month's incubation period in soil cultures under optimum conditions of moisture and temperature (in an incubator) are very nearly equivalent to the amounts formed in soils in the field during a period of from 2 to 3 months.[1] Therefore, the "Incubation Period in Weeks" as shown in figure 1 should in

[1] Experiments testing out this point for Hawaiian soils under Hawaiian climatical conditions are now being instigated at this experiment station.

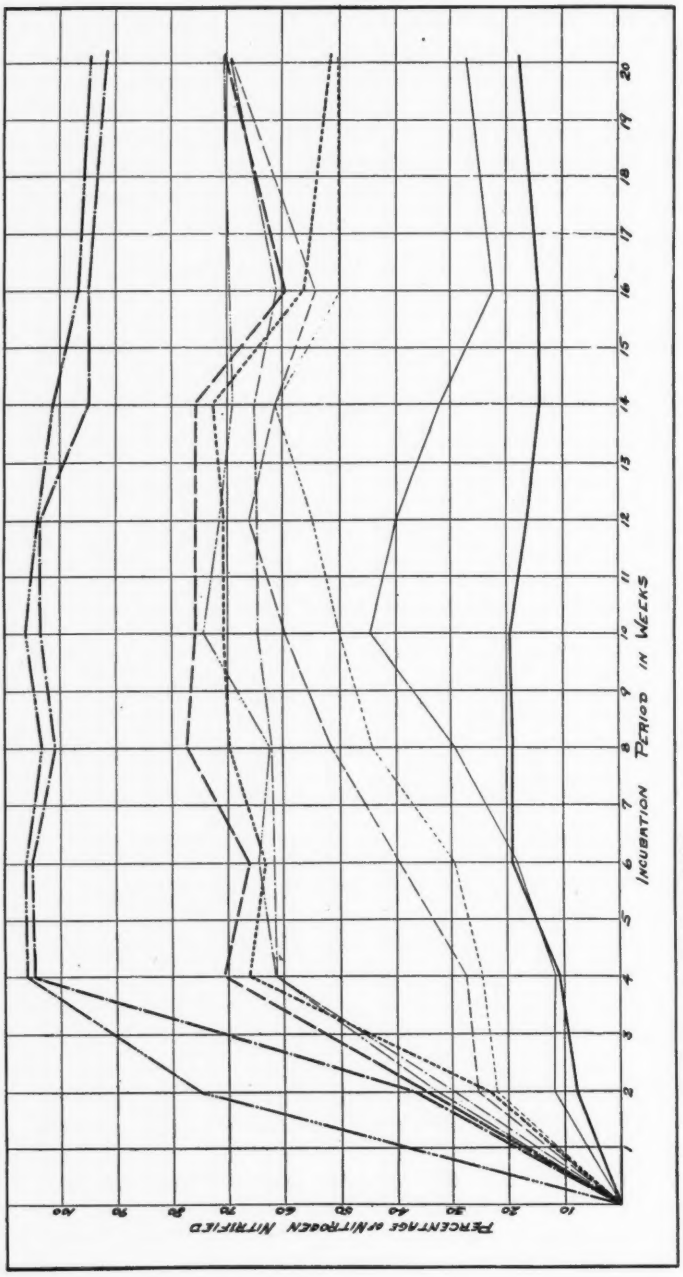


FIG. 1. CURVES SHOWING EFFECT OF CORAL SAND AND FINELY-GROUND CORAL LIMESTONE ON NITRIFICATION

all probability be multiplied by about 2 or 3 in each case if approximate field conditions are desired.

A number of very interesting facts are shown by a study of the data and graphs presented. Probably the most striking is the effect of the finely-ground coral limestone on the *rate* of nitrification. This is especially true where ammonium sulfate was used as the source of nitrogen (see heavy lines in figure 1). At the end of 2 weeks, only 8 per cent of the sulfate nitrogen was transformed where no lime was applied. Where exactly enough ground limestone to neutralize soil acidity was used, nearly 31 per cent was nitrified, and where twice this amount was added, 75 per cent of the sulfate nitrogen was converted into nitrate in this *previously acid* soil. The same general trend is noted where coral sand instead of ground limestone was used, but the increments of gain over the cultures without lime are here a little less than half the above.

At the end of one month, where ground limestone was used, all of the added sulfate nitrogen was nitrified, as well as a small amount of the soil's own organic nitrogen, while where coral sand was added only about 70 per cent of the added nitrogen was transformed. At no period of time after this was coral sand, either to exact neutrality or in twice this amount, able to effect a nitrification of much over 75 per cent of the sulfate nitrogen originally added. On the other hand, ground limestone, from the fourth to the fifteenth week, in all cases affected a complete nitrification of all added sulfate nitrogen. It will be noted that after about the fifteenth week there was a gradual dropping off of nitrate in all of the cultures. This is doubtless due in part to denitrification, in part to the complete use of all bases present by the nitrous and nitric acids formed by the nitrifying bacteria, and in part to the formation of other bacterial products which were inimical to continued active bacterial growth. As will also be seen, the additions of twice the required amounts of lime (either as ground limestone or as coral sand), had but slight advantages over those quantities needed to neutralize soil acidity exactly. The only pronounced exception is with the ground limestone at the start of the incubation period. Here an excess of lime appears to have accelerated considerably the initial bacterial action.

Where dried blood was substituted for ammonium sulfate as the carrier of nitrogen, the same general tendencies as above noted occurred (see light lines in figure 1), although the absolute percentages of added nitrogen nitrified are less. At the end of 4 weeks ground limestone effected over three times as much nitrification (over the no lime cultures) as did coral sand, but this ratio gradually narrowed with prolonged incubation until, at the end of 14 weeks, the coral sand was to the ground limestone as 8 is to 9. Continued incubation from this point had little effect on nitrate formation where sand was added, but there continued to be a slight increase with the finely-ground limestone. Double the required amounts of coral sand (where dried-blood nitrogen was used) had a far greater enhancing effect on nitrification than similar double

portions of the ground limestone, for at the end of 12 weeks twice the former gave approximately the same amount of nitrate formed as once the latter. The reason for this is probably to be found in the larger amount of *fine* material added in a double application of the coral sand, for, as this work clearly shows, the finer the material the more readily it corrects acidity.

The above discussion has been based on the *percentage* of added nitrogen transformed. Let us here briefly consider the *absolute amounts* of nitrate produced. It will be remembered that the same soil was used throughout, also that approximately equal amounts of nitrogen were in all cases added (40.5 mgm. as blood nitrogen and 42.4 mgm. as ammonium sulfate nitrogen). Table 3, shows definitely that, where no lime in any form is added, larger quantities of nitrogen are converted into nitrate from blood nitrogen than from sulfate nitrogen, but where *lime* of any description *is added* the *absolute reverse* is true. This is readily explained. Where ammonium sulfate only is applied, the basic ammonium radicle (NH_3) is in part converted into nitrate, leaving the acid sulfate radicle (SO_3) free. The latter, combining with water (H_2O), immediately forms sulfuric acid (H_2SO_4). Thus, as slow nitrification progresses the soil becomes more and more acid until, as shown in figure 1, at the end of 6 weeks such an excess of acid has accumulated that from then on nitrification gradually falls off to the end of the experiment. On the other hand, when blood alone is applied, vigorous ammonification at once sets in with an evolution of far more basic ammonium carbonate than the sluggish nitrifying bacteria can oxidize. The result is that much of the soil acidity is at once neutralized, which in turn renders conditions more favorable to active nitrification. Thus *at first* the nitrification of blood is fairly rapid (fig. 1), but a time eventually comes when all of this basic ammonium carbonate is either nitrified or neutralized (at the end of 10 weeks' incubation period). From here on will be noticed a very rapid falling off in the amounts of nitrate formed, which continues to the end of the experiment. Stated concisely, organic forms of nitrogen are always more quickly and readily nitrified in acid soils than are mineral ammonium salts.

A few valuable facts are gleaned from a study of the figures presented in table 3 which are impossible of graphic representation in figure 1.

When we consider the soil's own organic nitrogen (no additions of either dried blood or ammonium sulfate) we find that it makes practically no difference as to absolute amounts of nitrogen nitrified whether coral sand or finely ground limestone is used, although slightly quicker action is secured from applications of the latter. Averaging all of the figures throughout the 20 weeks' test we have, where sand was applied, 1.75 per cent of the soil's nitrogen nitrified; where ground limestone was used, 1.86 per cent, and where no lime was employed 0.36 per cent. The reason for the close approach of sand to ground limestone where the soil's own organic nitrogen was concerned is probably to be found in the fact that here such *small* amounts of nitric acid are produced that enough very fine material is present in the sand added to neu-

tralize it, as well as the more active soil acidity. Experiments pertaining to the effect of *partially* neutralizing soil acidity on the nitrification of the soil's own organic nitrogen, sulfate nitrogen and blood nitrogen, are now in progress at this station.

Considering absolute amounts of nitrogen made available (transformed to nitrate), it is noteworthy that an application of the required amount of lime to this soil *without added nitrogen* supplies *more nitrate* to the growing cane through the nitrification of the soil's own organic nitrogen than an application of $1\frac{1}{2}$ tons per acre of ammonium sulfate *without lime*, and four-fifths as much as an application of 1 ton of dried blood *without lime*, provided moisture and temperature conditions are suitable. In other words, lime and no fertilizer (except nitrates) could here pay better than fertilizer and no lime.

CONCLUSIONS

Taking the average figures for each 2-week incubation period throughout the 20 weeks (see last two columns of figures in table 3) the following conclusions may be drawn

1. Where no additions of nitrogen are made, coral sand and ground coral limestone are about equally effective in enhancing the nitrification of an acid soil's own organic nitrogen. After neutralizing Hawaii acid soils, the average amounts of nitrate formed over a period of 5 months under optimum conditions are comparatively small.

2. The increment of gain in nitrate formed over the soil exactly neutralized, due to adding twice the amounts of lime required (either as coral sand or as ground limestone), is too slight to warrant double applications. Twice the required amounts of coral sand effect a greater increase in nitrate produced over the soils exactly neutralized than do twice the amounts of finely-ground coral limestone.

3. Where *coral sand* was used in sufficient amounts to bring the soils to exact neutrality, the following percentages of gain over the soils to which no lime in any form was added, are indicated:

	per cent
No nitrogen added (soil's own nitrogen)	486
Dried blood nitrogen added	165
Ammonium sulfate nitrogen added	398

4. Where *finely-ground coral limestone* was used to neutrality, the following percentages of gain over the "no lime" cultures are indicated:

	per cent
No nitrogen added (soil's own nitrogen)	518
Dried blood nitrogen added	235
Ammonium sulfate nitrogen added	608

5. Comparing the average percentage of increased nitrate production, due to neutralizing exactly the soil with coral sand, with that brought about by

the addition of finely-ground coral limestone, where both ammonium sulfate nitrogen and dried blood nitrogen were supplied, we have, as a general average over the entire incubation period of 5 months, an increase of 281 per cent due to sand applications and an increase of 421 per cent due to ground limestone applications. From these figures a simple ratio shows that, when lime availability is measured in the soil by enhanced nitrification, 1 ton of the finely-ground limestone is practically equivalent, in neutralizing soil acidity, to 1.5 tons of the best grade of coral sand.

REFERENCES

(1) BURGESS, P. S. 1917 A study of the principal plantation soil types as found on the Island of Hawaii. Hawaiian Sugar Planters' Assn. Exp. Sta. Bul. 45.

(2) LIPMAN, C. B., AND SHARP, L. T. 1912 Studies on the phenoldisulphonic acid method for determining nitrates in soils. Univ. Cal. Pub. Agr. Sci., v. 1, no. 2.

(3) POTTER, R. S., AND SNYDER, R. S. 1915 Determination of amino acids and nitrates in soils. Iowa Agr. Exp. Sta. Research Bul. 24, p. 340–342.

VEGETATION EXPERIMENTS ON THE AVAILABILITY OF TREATED PHOSPHATES

JACOB G. LIPMAN AND HARRY C. McLEAN

New Jersey Agricultural Experiment Stations

Received for publication September, 1917

The authors of this paper suggested in an earlier publication[1] the use of sulfur as a means for making available the phosphorus in ground phosphate rock. They showed that ground sulfur may be used successfully for this purpose. Experiments conducted since then have confirmed the earlier results and will be reported at a later date. It is the purpose of the authors to record in this paper the results secured in vegetation experiments from ground phosphate rock otherwise untreated, from ground phosphate rock previously composted with sulfur, and from acid phosphate. In arranging for these vegetation experiments, it was felt that the availability of the phosphate rock previously composted with sulfur should be demonstrated not merely by chemical tests, but also by actual tests with plants. Accordingly, quantities of ground phosphate rock (floats), ground phosphate rock previously composted with sulfur, and acid phosphate, containing equivalent amounts of phosphorus, were used in the pot experiments described in the following pages. The experiments were carried out by means of glazed earthenware pots of 1 gallon capacity. In the series in which cabbage was grown, however, 2-gallon pots were used. In each pot there was placed 10 pounds of white quartz sand and, in addition, 5 gm. of calcium carbonate, 1 gm. of potassium sulfate, 0.25 gm. of magnesium sulfate, 0.12 gm. of ferric sulfate and 1.5 gm. of sodium nitrate. In order to eliminate sulfur as a limiting factor, pots 1, 2, 3 and 4 in each series received additions of calcium sulfate equivalent in amount to that contained in the sulfur-floats mixture. The additions described above provided, therefore, all of the essential plant-food constituents except phosphorus. The special treatment consisted of applications of no phosphorus in pots 1 and 2 of each series; of ground phosphate rock in pots 3 and 4 of each series; of ground phosphate rock and sulfur previously composted in pots 5 and 6 of each series, and of acid phosphate in pots 7 and 8 of each series. The amount of phosphorus actually furnished was equivalent in each case to that contained in 1 gm. of floats. The fertilizer materials were added to the 10 pounds of sand used in each pot and thoroughly mixed with the sand in a flat pan before they were transferred to the pots. However, in the series in which cabbage was grown,

[1] Lipman, J. G., McLean, H. C., and Lint, H. C., 1916. Sulfur oxidation in soils and its effect on the availability of mineral phosphates. *In* Soil Sci., vol. 2, no. 6, p. 499–538.

20 pounds of sand and double quantities of the different fertilizer materials were employed. There were, in all, 11 series of 8 pots each. The crops grown in the tests included cabbage, rape, buckwheat, soybeans, corn, sorghum, barley, millet, turnips, wax beans and alfalfa. The plants grown in each series were thinned out to leave the same number of plants per pot. The number of these varied with the crop grown. The moisture content was maintained during the experiment at about 10 per cent.

It was observed soon after germination that the plants in the pots which received no additions of phosphorus, and in those which received additions of floats, made very slight growth. On the other hand, the plants in the pots which had received additions of floats previously composted with sulfur, and in those treated with acid phosphate, made very good growth. After several weeks the crops were photographed and harvested. After thorough drying, records were made of the dry weights of the plants harvested from each pot. These weights are recorded in table 1. After the first crop was harvested, the sand in each pot was thoroughly stirred with a trowel and a second application of 1 gm. of sodium nitrate was made in order to preclude the possibility of nitrogen becoming the limiting factor in production. Without further treatment a residual crop was grown in all but three of the series. The residual crops were later harvested, dried and their weights recorded. A record also of these weights appears in table 1. Photographs showing the appearance of the plants in three of the series are given in plate 1.

An examination of the table will show that the different crops showed marked variations in their ability to utilize the phosphorus in the floats. It is particularly interesting to note that buckwheat was able to make very good growth in pots 3 and 4 in which floats were the only source of phosphorus. Also, cabbage and rape were able to utilize the phosphorus of floats to a fairly marked extent. On the other hand, turnips, barley, millet, soybeans, wax beans, alfalfa, corn and sorghum were unable to utilize the phosphorus in floats to an appreciable extent. These results indicate a practical application in that floats, now unquestionably the cheapest source of phosphorus, might be used for the growing of buckwheat, the latter to be turned under as a green manure. In this manner, buckwheat might be used as a means for supplying phosphorus at a low cost to small grains, corn and some of the legumes.

It might also be noted that the floats previously composted with sulfur became a very satisfactory source of phosphorus. This was, of course, expected, since analyses of the composted mixtures of floats and sulfur showed that in a period of 30 weeks most of the phosphorus in the floats had become available, according to the method of the Association of Official Agricultural Chemists. It will be observed that, in the case of the rape, turnips, buckwheat, barley, millet, soybeans, wax beans and sorghum, the floats-sulfur compost was as effective as the acid phosphate. Where these crops were followed by residual crops, viz., millet, corn and sorghum, the floats-sulfur compost also showed up to good advantage. On the other hand, in the case

TABLE 1

The influence of treated phosphates on the yields of dry matter

POT NUMBER	TREATMENT	FIRST CROP			RESIDUAL CROP			TOTAL INCREASE OVER CHECK —BOTH CROPS
		Weight of crop	Average	Increase over check	Weight of crop	Average	Increase over check	
		Cabbage			Corn			
		grams	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*
1	Check (no phosphorus).....	1.50			3.40			
2	Check (no phosphorus).....	1.10	1.30		4.00	3.70		
3	Raw rock phosphate.....	4.25			4.20			
4	Raw rock phosphate.....	3.40	3.83	2.53	3.75	3.98	0.28	2.81
5	Compost.....	9.35			17.00			
6	Compost.....	6.30	7.83	6.53	19.40	18.20	14.50	21.03
7	Commercial acid phosphate..	11.55			39.25			
8	Commercial acid phosphate..	13.03	12.29	10.99	40.75	40.05	36.35	47.34
		Rape			Millet			
1	Check (no phosphorus).....	1.20			0.20			
2	Check (no phosphorus).....	4.90	3.05		0.85	0.53		
3	Raw rock phosphate.....	3.85			0.35			
4	Raw rock phosphate.....	6.70	5.28	2.23	1.25	0.80	0.27	2.50
5	Compost.....	8.50			9.20			
6	Compost.....	8.90	8.70	5.65	8.15	8.68	8.15	13.80
7	Commercial acid phosphate..	8.46			9.85			
8	Commercial acid phosphate..	8.35	8.41	5.36	10.00	9.93	9.40	14.76
		Turnips			Millet			
1	Check (no phosphorus).....	0.25			0.40			
2	Check (no phosphorus).....	0.25	0.25		0.40	0.40		
3	Raw rock phosphate.....	0.70			0.60			
4	Raw rock phosphate.....	0.50	0.60	0.35	0.60	0.60	0.20	0.55
5	Compost.....	9.75			7.50			
6	Compost.....	10.40	10.08	9.83	7.25	7.38	6.98	16.81
7	Commercial acid phosphate..	10.80			9.00			
8	Commercial acid phosphate..	9.25	10.03	9.78	9.00	9.00	8.60	18.38
		Buckwheat			Millet			
1	Check (no phosphorus).....	5.20			0.30			
2	Check (no phosphorus).....	5.40	5.30		0.25	0.28		
3	Raw rock phosphate.....	12.20			2.85			
4	Raw rock phosphate.....	12.90	12.55	7.25	1.60	2.23	1.95	9.20
5	Compost.....	13.40			8.55			
6	Compost.....	13.80	13.60	8.30	10.25	9.40	9.12	17.42
7	Commercial acid phosphate..	14.00			11.50			
8	Commercial acid phosphate..	14.80	14.40	9.10	10.75	11.13	10.85	19.95

TABLE 1—(Continued)

POT NUMBER	TREATMENT	FIRST CROP			RESIDUAL CROP			TOTAL INCREASE OVER CHECK—BOTH CROPS
		Weight of crop	Average	Increase over check	Weight of crop	Average	Increase over check	
		Barley			Corn			
		grams	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*
1	Check (no phosphorus).....	1.05			3.50			
2	Check (no phosphorus).....	1.10	1.08		2.75	3.13		
3	Raw rock phosphate.....	1.55			3.20			
4	Raw rock phosphate.....	1.25	1.40	0.32	3.15	3.18	0.05	0.37
5	Compost.....	7.60			6.25			
6	Compost.....	8.05	7.83	6.75	4.25	5.25	2.12	8.87
7	Commercial acid phosphate..	8.00			6.80			
8	Commercial acid phosphate..	7.80	7.90	6.82	5.70	6.25	3.12	9.94
		Millet			Sorghum			
1	Check (no phosphorus).....	0.35			0.65			
2	Check (no phosphorus).....	0.45	0.40		0.75	0.70		
3	Raw rock phosphate	0.55			0.90			
4	Raw rock phosphate.....	0.60	0.58	0.18	0.90	0.90	0.20	0.38
5	Compost.....	16.00			2.75			
6	Compost.....	14.55	15.28	14.88	1.50	2.13	1.43	16.31
7	Commercial acid phosphate..	15.20			2.10			
8	Commercial acid phosphate..	15.30	15.25	14.85	0.75	1.43	0.73	15.58
		Soy Beans			Corn			
1	Check (no phosphorus).....	9.80			3.08			
2	Check (no phosphorus).....	10.15	10.48		4.60	3.84		
3	Raw rock phosphate.....	8.90			4.35			
4	Raw rock phosphate.....	10.95	9.93	(−0.55)	3.95	4.15	0.31	(−0.24)
5	Compost.....	27.70			10.35			
6	Compost.....	25.50	26.60	16.12	12.15	11.25	7.41	23.53
7	Commercial acid phosphate..	24.10			11.20			
8	Commercial acid phosphate..	24.50	24.30	13.82	12.30	11.75	7.91	21.73
		Wax Beans			Millet			
1	Check (no phosphorus).....	7.70			0.35			
2	Check (no phosphorus).....	7.50	7.60		0.35	0.35		
3	Raw rock phosphate.....	6.70			0.85			
4	Raw rock phosphate.....	9.10	7.90	0.30	0.65	0.75	0.40	0.70
5	Compost.....	12.20			7.00			
6	Compost.....	12.60	12.40	4.80	4.00	5.50	5.15	9.95
7	Commercial acid phosphate..	13.10			6.00			
8	Commercial acid phosphate..	12.30	12.70	5.10	6.25	6.13	5.78	10.88

TABLE 1—(Concluded)

POT NUMBER	TREATMENT	FIRST CROP			RESIDUAL CROP			TOTAL INCREASE OVER CHECK—BOTH CROPS
		Weight of crop	Average	Increase over check	Weight of crop	Average	Increase over check	
		Alfalfa						
		grams	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*
1	Check (no phosphorus).....	0.20						
2	Check (no phosphorus).....	0.15	0.18					
3	Raw rock phosphate.....	0.18						
4	Raw rock phosphate.....	0.15	0.17	(−0.01)				
5	Compost.....	1.80						
6	Compost.....	1.75	1.78	1.60				
7	Commercial acid phosphate..	4.30						
8	Commercial acid phosphate..	4.30	4.30	3.12				
		Corn						
1	Check (no phosphorus).....	3.00						
2	Check (no phosphorus).....	2.40	2.70					
3	Raw rock phosphate.....	3.35						
4	Raw rock phosphate.....	2.80	3.08	0.38				
5	Compost.....	10.70						
6	Compost.....	11.50	11.10	8.40				
7	Commercial acid phosphate..	14.80						
8	Commercial acid phosphate..	13.60	14.20	11.50				
		Sorghum						
1	Check (no phosphorus).....	0.70						
2	Check (no phosphorus).....	0.40	0.55					
3	Raw rock phosphate.....	1.20						
4	Raw rock phosphate.....	0.90	1.05	0.50				
5	Compost.....	9.90						
6	Compost.....	12.25	11.08	10.53				
7	Commercial acid phosphate..	12.20						
8	Commercial acid phosphate..	10.90	11.55	11.00				

of cabbage followed by corn, the acid phosphate was distinctly superior to the floats-sulfur compost. The discrepancy in this particular series is difficult to account for and will be made the subject of further study. Meanwhile, it is sufficient to state in this preliminary paper that floats properly composted with ground sulfur may become a source of available phosphorus, as shown both by chemical analyses and by vegetation tests.

SUMMARY

1. It has been shown in this paper that some crops can utilize the phosphorus in floats to good advantage. This is particularly true of buckwheat.

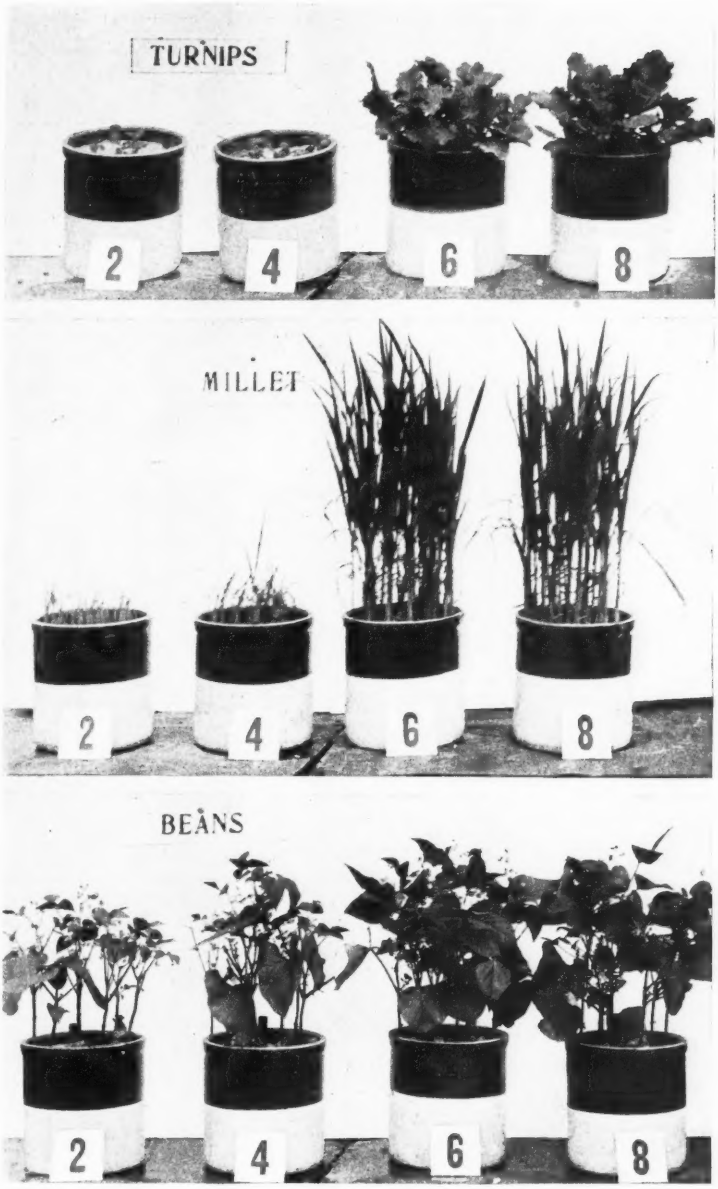
2. The ability of buckwheat to use effectively the phosphorus of ground, but otherwise untreated, phosphate rock suggests that this crop may be made a

valuable green manure and employed to increase the content in the soil of organic matter and of available phosphorus.

3. Ground phosphate rock properly composted with ground sulfur, becomes a source of available phosphorus and may be employed to advantage as a substitute for acid phosphate.

PLATE 1

Pot 2, no phosphorus; pot 4, floats; pot 6, compost; pot 8, commercial acid phosphate.


TURNIPS
2
4
6
8
MILLET
2
4
6
8
BEANS
2
4
6
8